TRANSIENT SIMULATION INTERFACE FOR RELAY TESTING

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SUMMARY

A simplified relay test system based on a personal computer is described. The system tests typical relays under conditions which simulate those in the field. EMTP software is used to generate specific fault test waveforms. The waveforms are then imposed on a relay by a power amplifier under PC control. In this way, a single relay can be tested as if it were present in any given location in a power system.

Introduction

Modern power systems must operate close to margin limits to minimize equipment costs, yet must meet increasing reliability requirements. Fast, dependable, well-coordinated protection devices are a critical issue. Electromechanical and electronic relays remain the main protection element. Their functions are increasingly sophisticated. They often control fast reclosing circuit breakers, and their coils are exposed to harmonic waveforms. Time-current characteristic curves are normally measured under sinusoidal conditions, and do not always reflect the actual behavior of a real device.

The objective of this project is to develop a simple, low-cost system to test relays and evaluate their operation in response to transient conditions on a faulted power network. The *dynamic testing* capability of this system can be used to evaluate relay performance, to test protection layouts, or to calibrate protection settings. The system can impose actual field fault recorder data, or simulated waveforms such as those obtained with the Electromagnetic Transients Program (EMTP) on a relay.

Previous Work

Several development projects for dynamic relay testing have been initiated over the past five years. In a typical arrangement [1], a "simulated transmission line," with three-phase protection at both ends, is constructed in the laboratory. The voltage and current sensing coils of each protective device are driven with appropriate waveforms to simulate the condition of interest. A total of six voltage-coil driving amplifiers, and six current-coil driving amplifiers are required in this configuration; the system is large and expensive.

In [1], the current drivers are implemented with switching amplifiers. They are supplied from a battery backup to permit very high momentary currents. The desired waveform is generated by a personal computer (PC). A similar system has been developed for the Western Area Power Administration (WAPA) [2]. In this case, the amplifiers are commercial units. An EMTP simulation is used to generate test waveforms, and a digital fault recorder is used to record the actual operating waveforms and results.

The simulated line approach is not new. There are several reports of such systems [3-6], with varying degrees of complexity. An extensive bibliography can be found in [7]. Models of individual devices within a protective network, including PTs and CTs, are important to relay operation. A recent test system developed at Texas A&M University [8,9] focusses largely on appropriate models of hardware. The models are used in conjunction with EMTP to simulate possible fault conditions.

System Requirements

A useful relay test system must examine the behavior of realistic devices in their proper context. For many protection arrangements, this requires a full double-ended transmission line. The test system must be able to use recorded fault data so that field problems can be reproduced and studied in the laboratory. It must be able to impose unusual harmonic conditions on the device under test. It should be able to drive the voltage and current coils fully up to fault levels.

Voltage, current, and frequency response

Most relay current coils present impedance burdens of either 2 Ω, 4 Ω, or 8 Ω to the driving CT when the tap settings are at a nominal 1 A point. Typical coils must track currents to at least 20 times the tap settings, but will begin to saturate by that level. For testing purposes, current capabilities need not exceed about 50 times the tap settings, a level near the one second intermittent rating of typical coils. At this level, the coil would be fully saturated, and the effect of additional current would be minimal. Figure 1, taken from an earlier preliminary report, shows examples for two relays.

The current coil characteristics resemble those of a conventional loudspeaker, and it is natural to consider audio amplifiers as possible drivers. An audio driver also provides wide frequency response. The drawback is the need for an amplifier capable of driving at least 20 A into a relay coil, and one able to cope with highly saturated cores. A 20 A_{RMS} current into a 4 Ω load, for example, represents 1600 W of audio power. It is important to recognize that this extreme power is needed only briefly during the relay pick-up time.

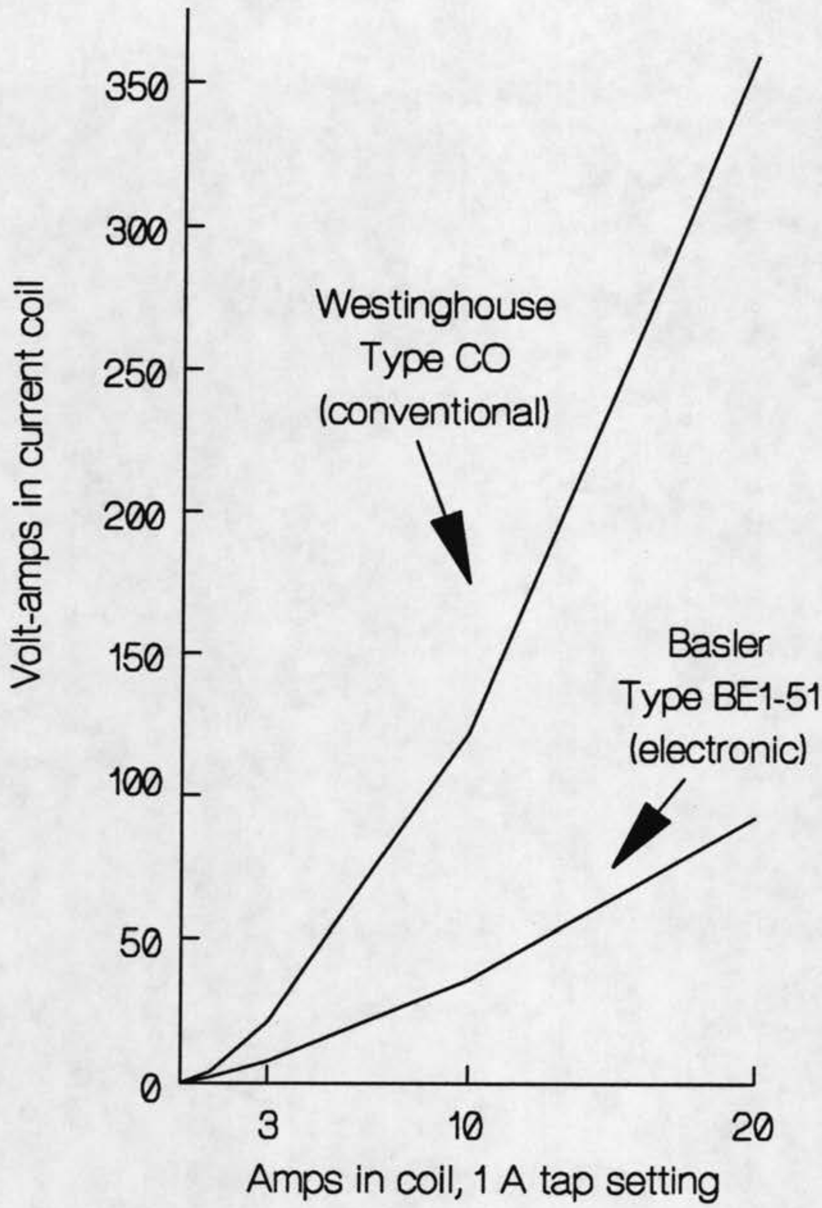

Figure 1 — Saturation effects on volt-amp burden of two relays

Distance or impedance relays will require voltage inputs. Voltage sensing coil requirements are likely to be less severe than current driver requirements. Saturation is not usually a problem for voltage coils, and the impedance remains very high throughout the measurement range. An inexpensive audio amplifier, coupled to the higher voltage and impedance with a transformer, would probably be well matched to the requirements.

There are several commercial audio amplifiers likely to be suitable for current-coil driving duties. For example, the Techron division of Crown, Inc. manufactures audio power amplifiers designed for industrial power supply applications. The model 7570 was obtained for this project. The capabilities, based on specifications and measurements, are summarized in Table I. This amplifier has frequency response down to dc, and can supply current into a short circuit. Continuous current coil driving at ten or more times the nominal 1 A setting is feasible. Short-term driving to at least 20 times the nominal setting is also possible.

Table I. Summary of Techron model 7570 specifications.

Characteristic	*Specification*
Frequency response	Dc - 100 kHz ±1 dB at 1 W load, Dc - 40 kHz at 1 kW load.
Output current (as measured)	±20 A continuous (even into short circuit), 28 A peak at 60 Hz, time-limited by thermal protection and line fuse.
Output voltage	±120 V peak.
Power and VA output	1.35 kW and 2 kVA continuous into 4 Ω load. Up to 3 kVA momentary was measured.
Phase response	Flat to about 1 kHz, worst-case conditions. Worst case signal delay 2.6 µs.
Harmonic distortion	Less than 0.001% THD, 20 - 400 Hz, into 8 Ω load at 600 W.
Operating mode	Differential input voltage waveform controls either the output current or the output voltage (selectable).
Input gain, measured for single-ended input	Adjustable up to 10 V/V or 8 A/V.
Protection	Internal thermal protection and circuit breaker. Short circuit load can be driven continuously without harm.
Slew rate	32 V/µs.
Current measurements	Built-in monitor provides 0.1-0.2 V/A signal.
Interconnection	Can be parallel or series connected with identical units to provide up to 20 kVA continuous.

Sensing hardware

To maximize the flexibility and simplicity of the test system, the main system controller is a standard personal computer equipped with a digital/analog input-output board. The specific board obtained for the project is the Computer Boards, Inc. model CIO-DDA06. The capabilities are summarized in Table II. This board does not have built-in A/D capability; an off-board circuit based on the Analog Devices AD7874 was designed to provide this function. The AD7874 adds an important dimension: it provides four channels of 12-bit analog input, with simultaneous sampling. This means that precise information about relative phase shifts and instantaneous power are preserved at the digital output of the A/D converter. It permits input analog sampling rates (for all four channels) of up to 30 kHz.

Table II. Computer input-output board specifications.

Characteristic	*Specification*
Digital I/O	24 lines, organized in two 8-bit I/O ports and two 4-bit I/O ports. TTL levels.
Analog output	6 D/A channels, 12-bit resolution. Unipolar or bipolar adjustment range.
Software	Direct support for BASIC or assembly language. Uses standard IBM PC auxiliary I/O ports.
Speed	Data rates of 20000 values per second (input or output) are typical on a 20 MHz 80386 PC.
Analog input	Off-board 4-channel A/D converter, 12-bit resolution, simultaneous sampling. Provides analog input at the digital ports.

Test method

Often, banks of single-phase relays are used for three-phase protection. Circuit breaker action is governed by the first relay in the bank that picks up. In principle, a single-phase test system could examine any possible behavior of such an arrangement. It is necessary only to determine the waveforms seen by each of the relays, and then test these waveforms sequentially on a single relay. An individual relay, after all, has access to limited information, and the information often must be altered based on the action of other relays in the simulated network.

The system described here is a single-phase test unit, which applies several test waveforms to the relay in rapid succession. Any given test can be altered based on operating results with prior waveforms.

Use of EMTP for fault response tests

The system has two operating modes. In a "failure analysis" mode, data from actual system fault conditions are imposed on a relay test set to either reproduce the system action or to determine more appropriate settings for the observed fault condition.

In a "simulation test" mode, waveforms from hypothetical faults are imposed on a relay to evaluate its performance and characteristics. For this mode, the objective of the project has been to establish a catalog of possible fault situations for a model three-phase system. EMTP (in this case, the public domain PC version called ATP) [10] permits detailed modelling of all types of faults. Here, EMTP has been used to model line-to-ground, line-to-line, and bolted three phase fault conditions, and to simulate the subsequent voltage and current transients. The waveforms are scaled as appropriate for system PT and CT ratios, then imposed on a single-phase relay to test the response to overcurrents. The complete process is iterative: once it is known which system relay will act first, simulation is continued from the initial trip point to determine further consequences of the interruption.

An example circuit for EMTP studies is shown in Figure 2. In this typical case, a 138 kV source with an internal X/R ratio of 15 supplies a nominal 5 MVA into a transmission bus. The line, connected through a relay set, comprises 20 miles of three-phase 795 MCM ACSR conductors with phase spacing of 20 feet and above-ground height of 50 feet. Both positive sequence and zero sequence impedances were modelled for the line, as shown in Table III. The load side of the transmission line is connected through a second relay set to a 10 MVA three-phase transformer with 8% impedance. The transformer is loaded at about 50% of capacity at 80% power factor.

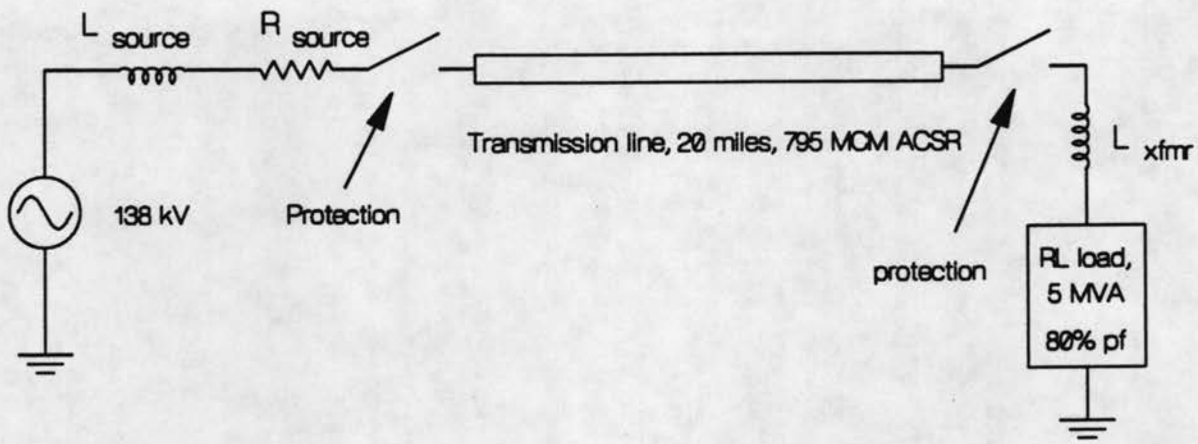

Figure 2. One-line system model for EMTP studies.

Table III. EMTP system impedances.

	Source impedance	*Load impedance*	*Transformer model*	*Positive sequence line impedance per meter*	*Zero sequence line impedance per meter*
R (Ω)	0.265	3809.	---	8.60×10^{-5}	2.60×10^{-4}
L (mH)	10.53	6062.	404.5	1.30×10^{-3}	4.20×10^{-3}
C (μF)	---	---	---	9.10×10^{-6}	5.10×10^{-6}

The six basic fault situations (three at each end of the line) were simulated by introducing additional switches into the model. The phase-to-ground fault was simulated by switching phase A to ground at the time of the phase A voltage peak. Results for a source-end line-to-ground fault are given in Figures 3-6. Figure 3 shows how the fault disturbs the other phases through stray coupling impedances. In Figure 4, the load-end voltage effect is given. High-frequency ringing caused by transmission line wavelength effects is clearly apparent. Figure 5 shows the source end current flow. The fault current is about 47 per unit on a 100 MVA base. Presumably, protective action would take place at the source end when the phase A current crosses zero. On the plot, interruption could occur ½ cycle after the

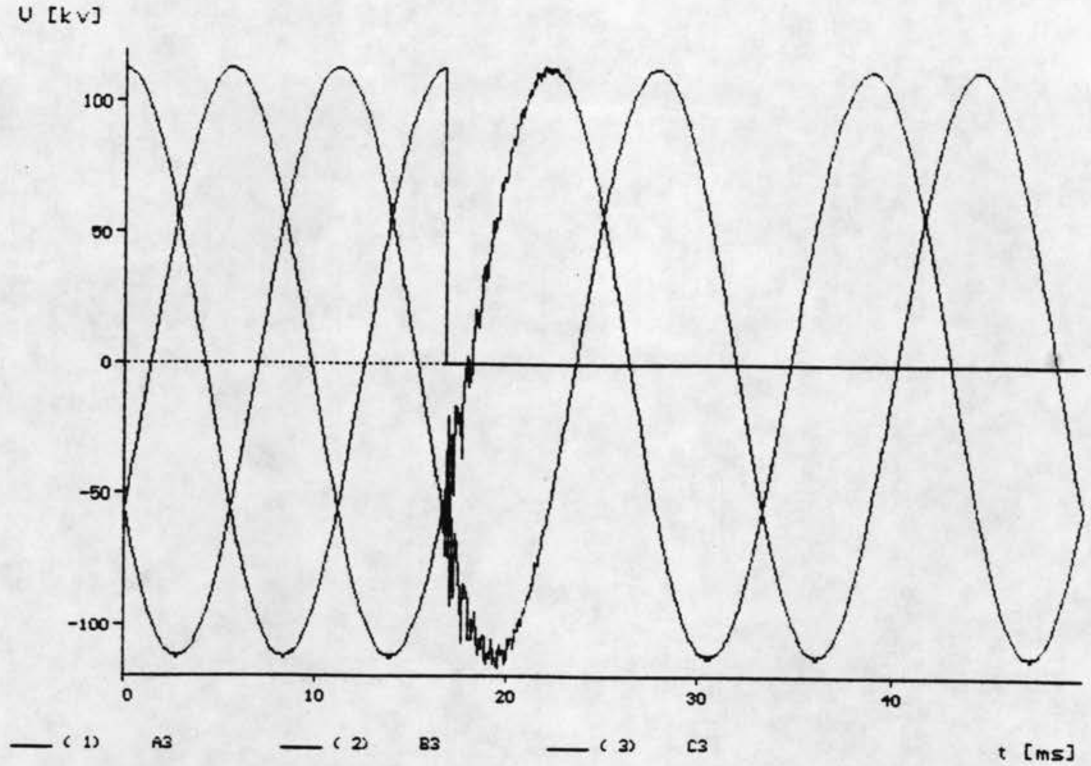

Figure 3. Voltages at source bus for line-to-ground fault.

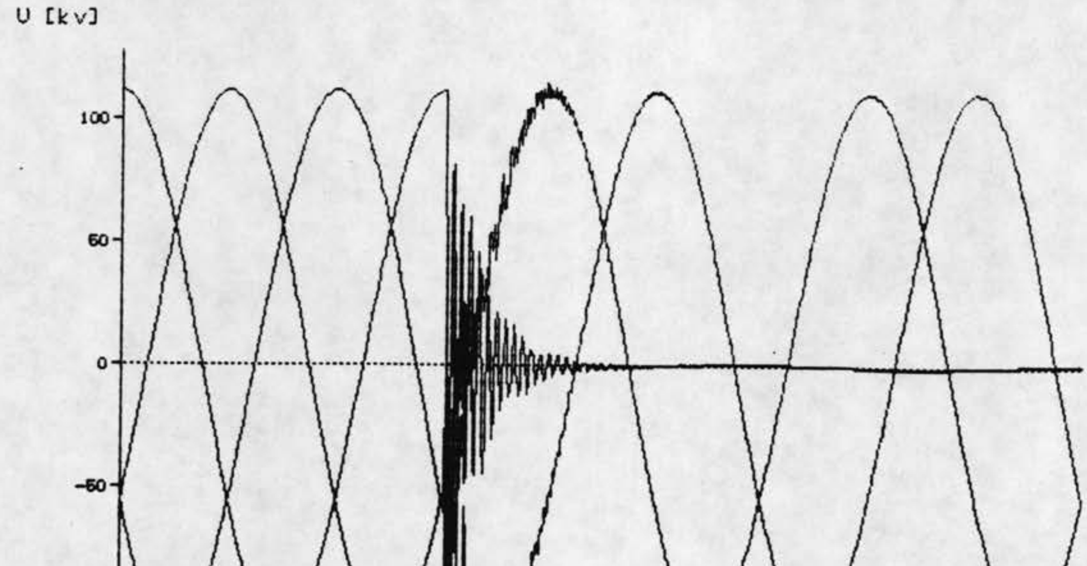

Figure 4. Voltages at load bus for line-to-ground fault.

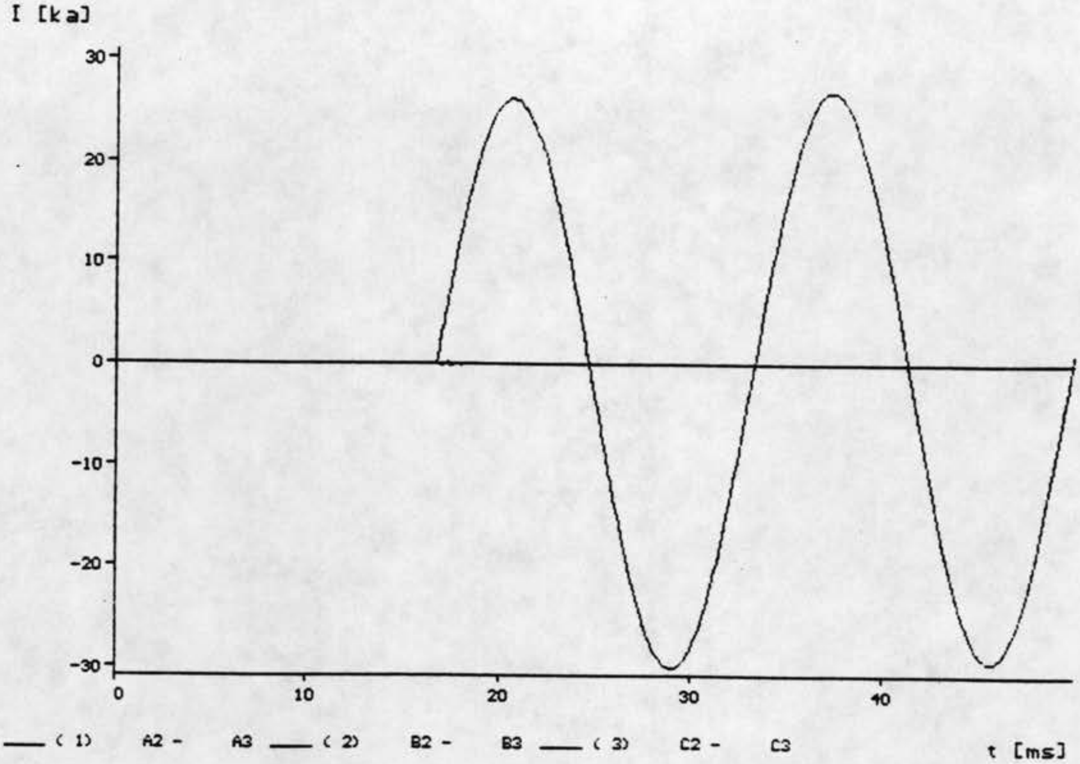

Figure 5. Currents at source bus for line-to-ground fault.

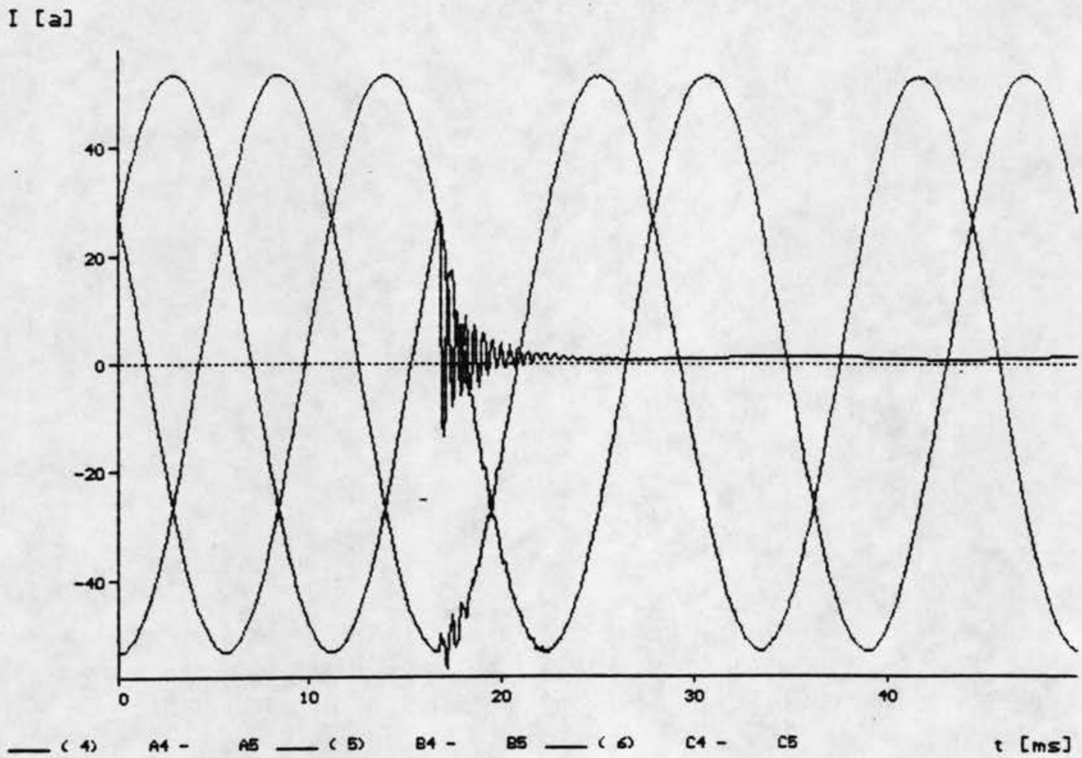

Figure 6. Currents at load bus for line-to-ground fault.

fault, or at a later zero crossing, depending on the relay dynamics and settings. Figure 6 shows the load end current flow. It is apparent that overcurrent protective relay action would not take place at the load end for this fault.

Line-to-line faults were produced by connecting phases A and C when the A-C line-to-line voltage was near its peak. The results for a source-end fault are given in Figures 7-10. Figures 7 and 8 show the source and load end voltages, respectively. Phase A and C voltages are equal after the fault occurs, so only two traces are seen after the fault. Again, the source end current rises rapidly to several thousand amps, as indicated in Figure 9. The dc offset caused by the fault would probably delay protective action in this situation, since the first zero crossing after high fault current occurs about 15 ms after the fault. The load-end currents, shown in Figure 10, again do not rise much, but the dc offset appears at the load end as well. The dc current might produce CT or relay saturation, which will change the pickup action.

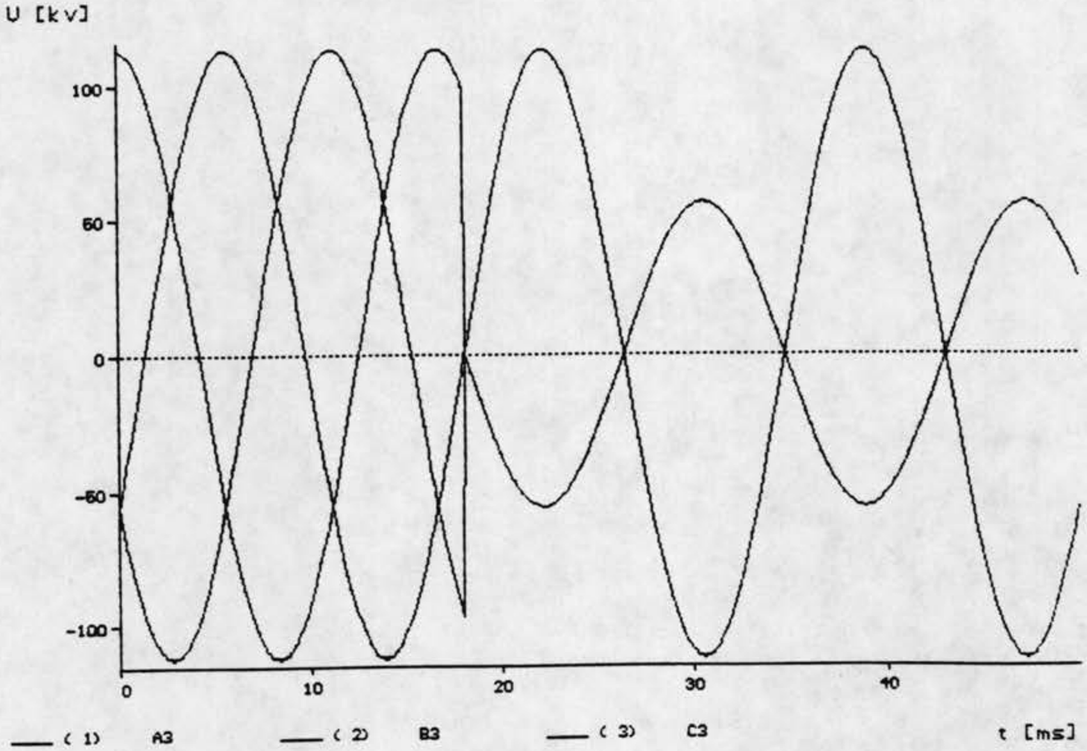

Figure 7. Voltages at source bus for line-to-line fault.

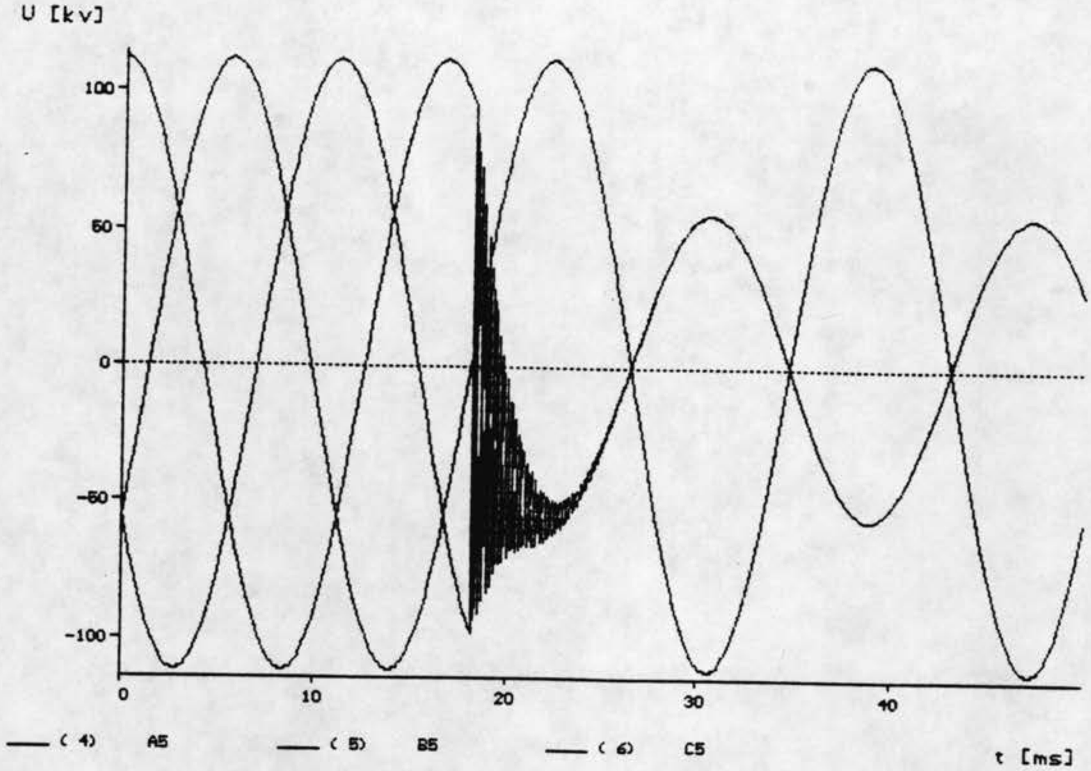

Figure 8. Voltages at load bus for line-to-line fault.

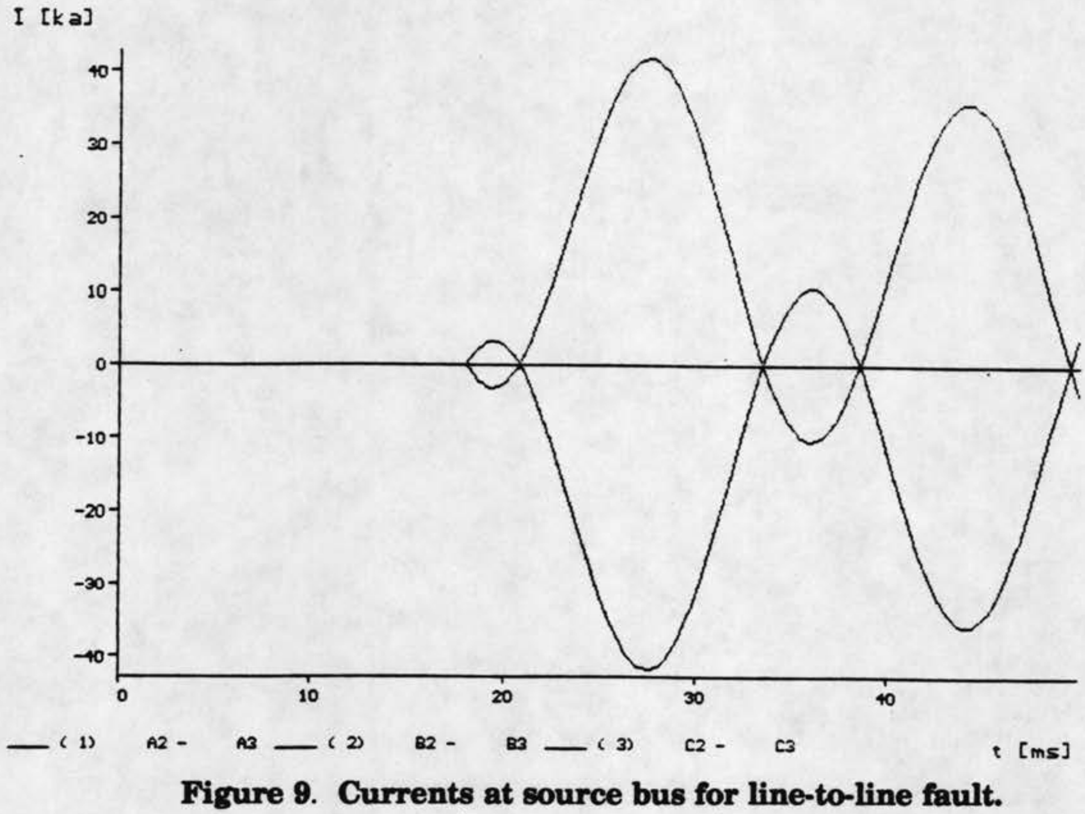

Figure 9. Currents at source bus for line-to-line fault.

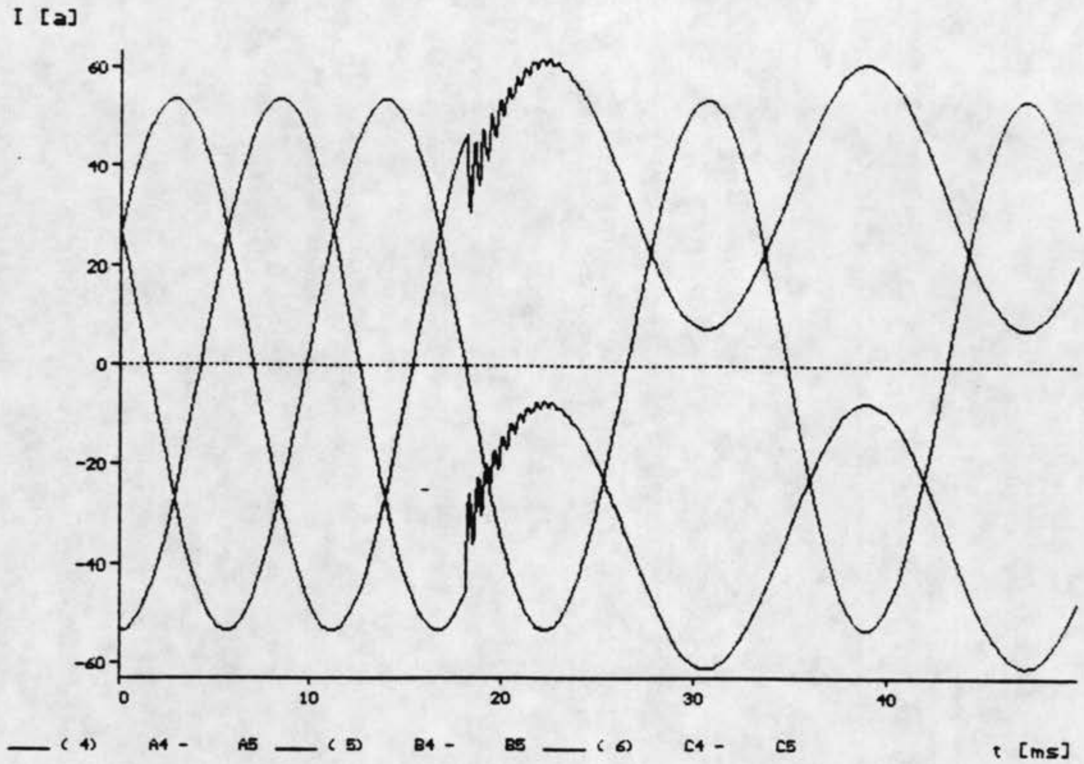

Figure 10. Currents at load bus for line-to-line fault.

The three-phase fault shorts all three phases at the same moment as in the line-to-line fault case. The results, again for a source end fault, are given in Figures 11-14. In this case, the voltage waveforms in Figures 11 and 12 rapidly go to zero. Also, source-end current rises into the kiloamp range. Timing of the protective action would depend on relay settings, of course. In this case, the first fault current zero crossing occurs about 5.3 ms post-fault, and protective action could take place there, or at later crossings. The load end current is almost purely dc during the fault, and there might be concern about how the relays at the load end will react.

An EMTP command set for the single line-to-ground fault is given in the Appendix. Given the general character of EMTP, nonlinear loads and nonsinusoidal currents could have been simulated for their fault characteristics. More complete power system models are straightforward in this system. Protective action would also be defined as a set of switches, each acting at a current zero crossing as computed from test results. The small number of parameters makes it straightforward to make fault behavior consistent with relay action.

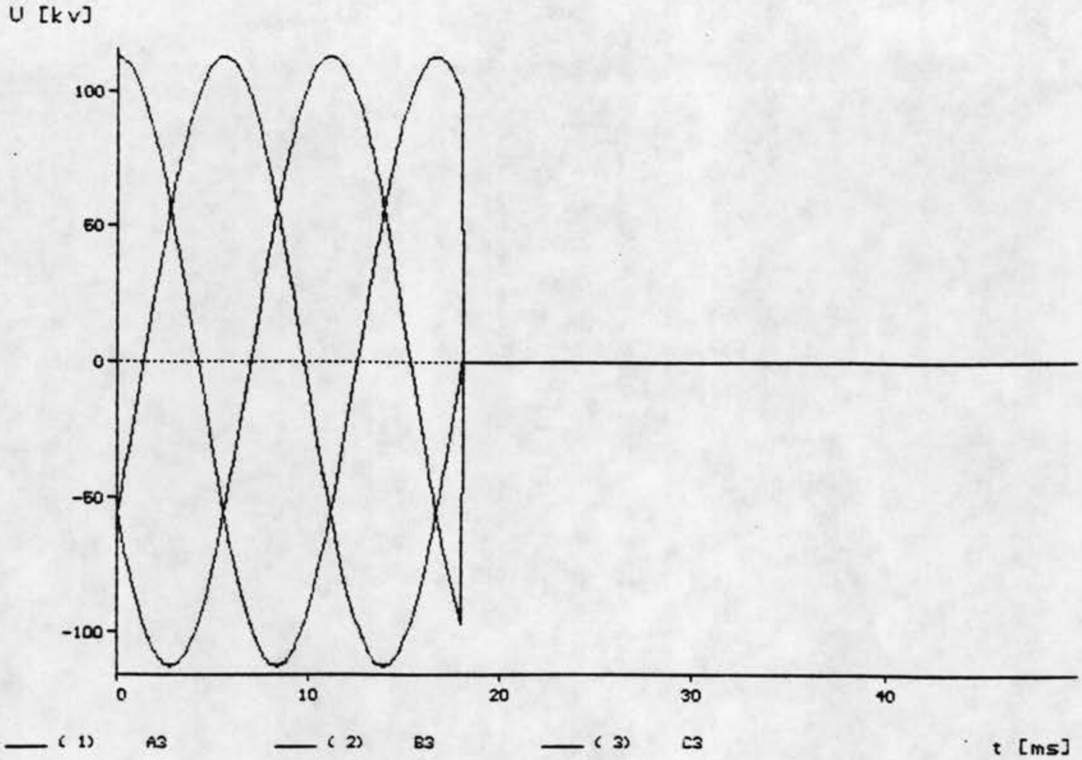

Figure 11. Voltages at source bus for three-phase fault.

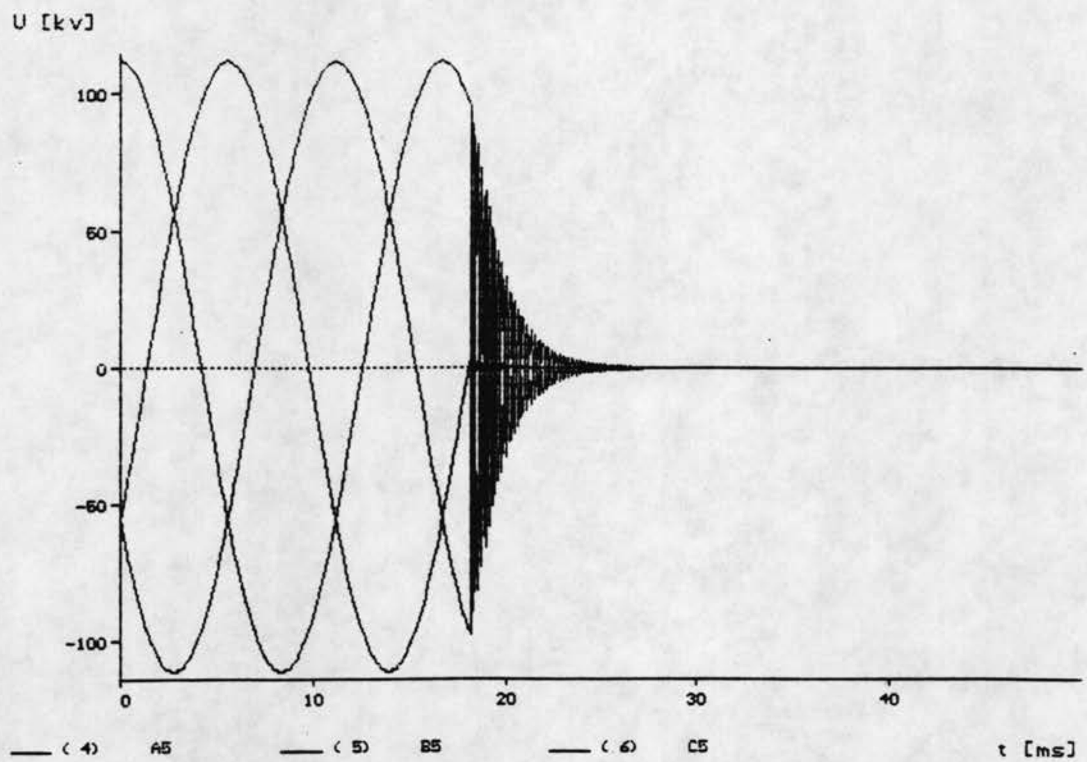

Figure 12. Voltages at load bus for three-phase fault.

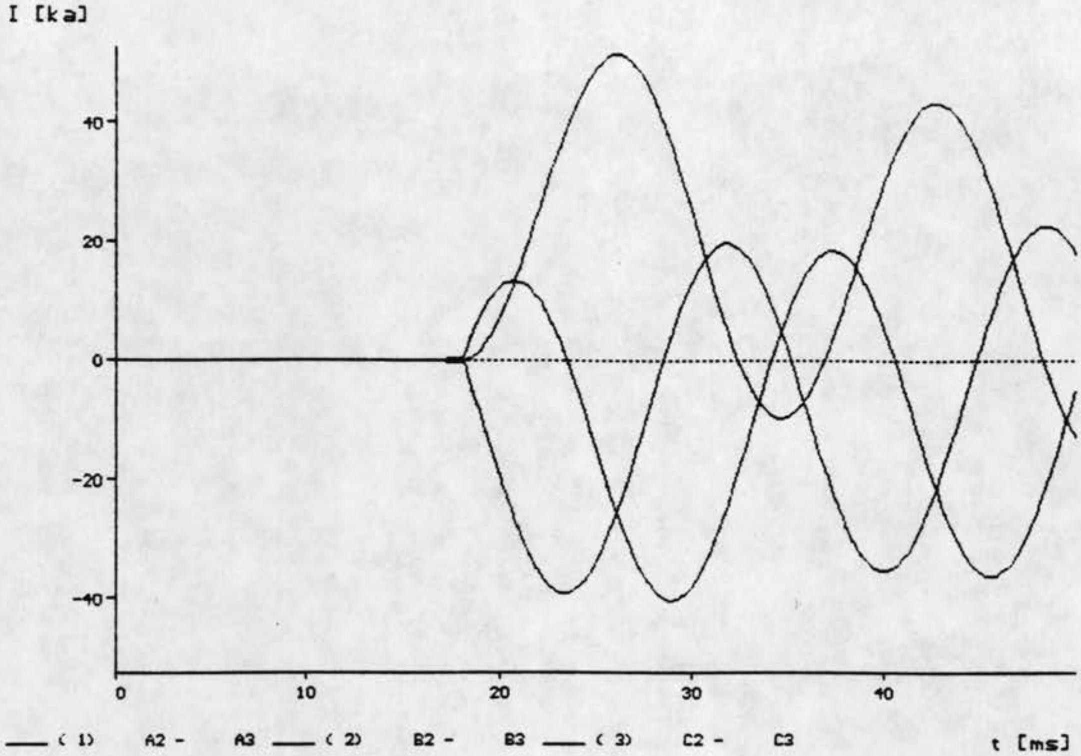

Figure 13. Currents at source bus for three-phase fault.

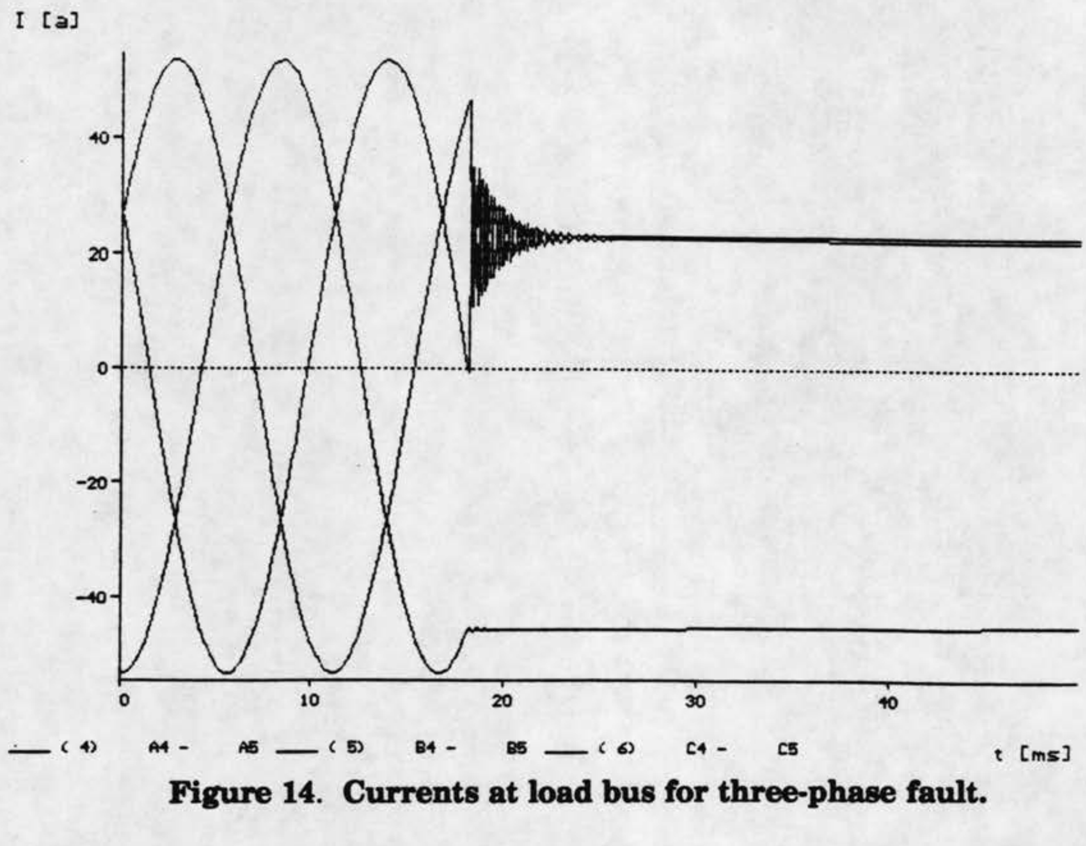

Figure 14. Currents at load bus for three-phase fault.

System Configuration

The test system arrangement is given in Figure 15. Some of the circuit details are provided in the Appendix. Only overcurrent relays were available for study; the voltage coil driver shown was not implemented. The PC serves as a waveform generator, data recorder, and computational engine. If true polyphase relays are used, the system shown can support them with minimal changes, since the I/O board permits simultaneous output on all the D/A ports. Of course, additional voltage and current driver amplifiers would be required to test three-phase relays.

The system user performs an EMTP simulation or selects a stored fault waveform. Waveform data for voltage and current are sent to analog ports on the CIO-DDA06 card. The waveforms serve as the control inputs to the voltage and current driver amplifiers. An interrupt routine monitors the relay contact status at a digital port. The default arrangement would wait up to a specified time limit for relay pick-up. Optical motion sensors can be used if the relay permits such an arrangement. In this case, a given test will continue as long as the relay disk is moving.

The report would provide current and voltages traces during the relay delay. Time-

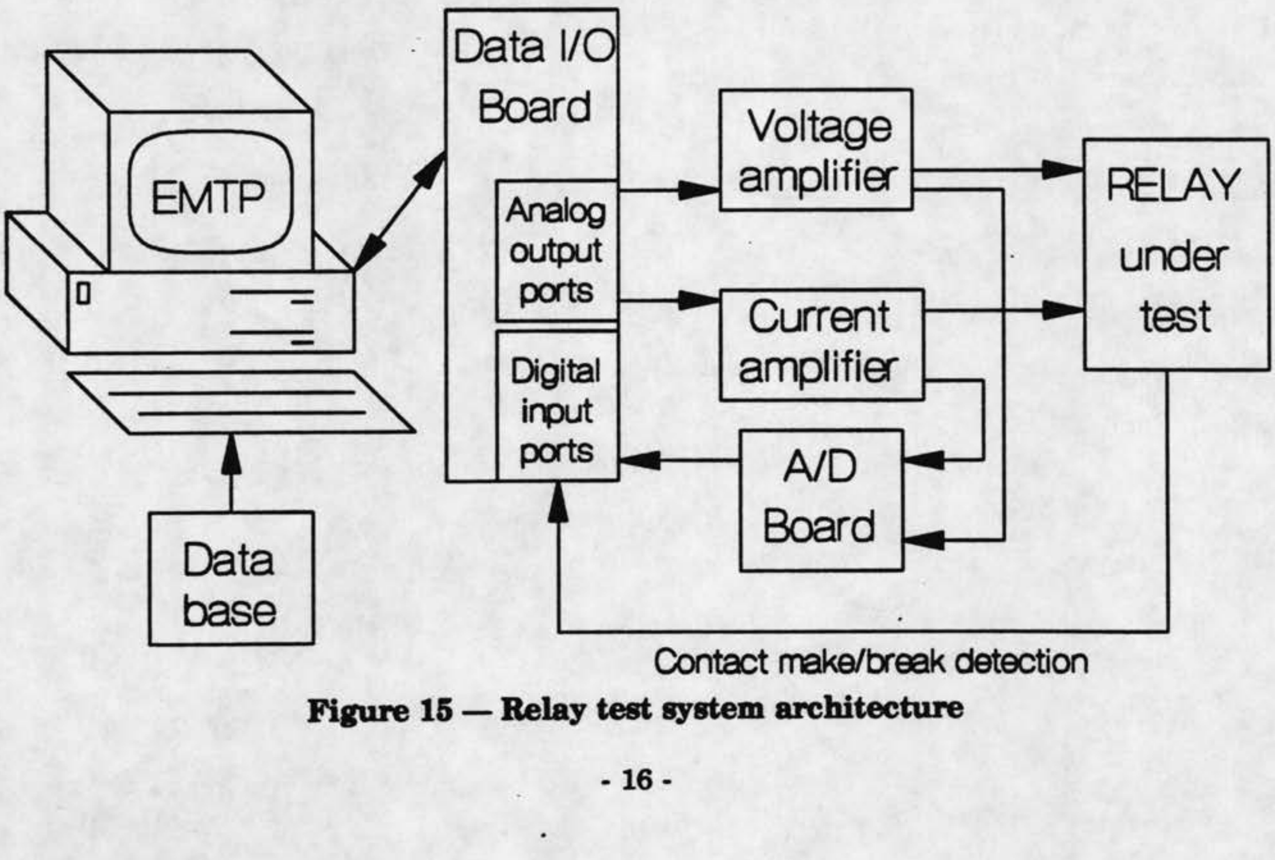

Figure 15 — Relay test system architecture

current products and similar information can be computed during the fault. The user should provide data about circuit interrupter speed. From the imposed waveforms and the interruption delay, the PC determines the time of the zero crossing at which interruption would be expected to occur. The report therefore includes relay pick-up time and expected circuit interruption time.

A flowchart of the planned software is shown in Figure 16. In failure analysis mode, the user selects a test case from a fault or test database. The test case will probably contain several waveforms for the various phases and measurement locations. The recommended data format is from the recent COMTRADE power system data exchange standard [11]. In simulation test mode, the waveforms would be computed by EMTP.

Once a test case is selected, the waveforms must be imposed on the relay under test. This process is sequential and automatic in the failure analysis mode. Depending on the relay type, a specific voltage coil waveform and current coil waveform are extracted from the test case data, then applied to the device. The computer monitors contact pickup, as well as the imposed waveforms, to determine relay behavior. In the simulation test case, the various waveforms are applied to the relay in quick succession. The computer then determines the first interruption time. A new simulation must be performed beginning at the interruption point to determine the expected waveforms.

Examples

The phase A source end current waveform of Figure 5 serves to illustrate part of the relay test process. The output information from EMTP was converted to a list of data for the I/O board with the program CONVD2A.BAS, a BASIC program provided in the Appendix. A program to convert COMTRADE data into the necessary digital list would be similar. This procedure creates a raw data file called I_a2g.D2A (the name indicates data for the current given a phase A to ground fault test). The program SEND_D2A.BAS, also given in the Appendix, is a very fast module capable of sending data out of the I/O board analog port. A compiled version of this code was able to generate an analog signal from an entire EMTP

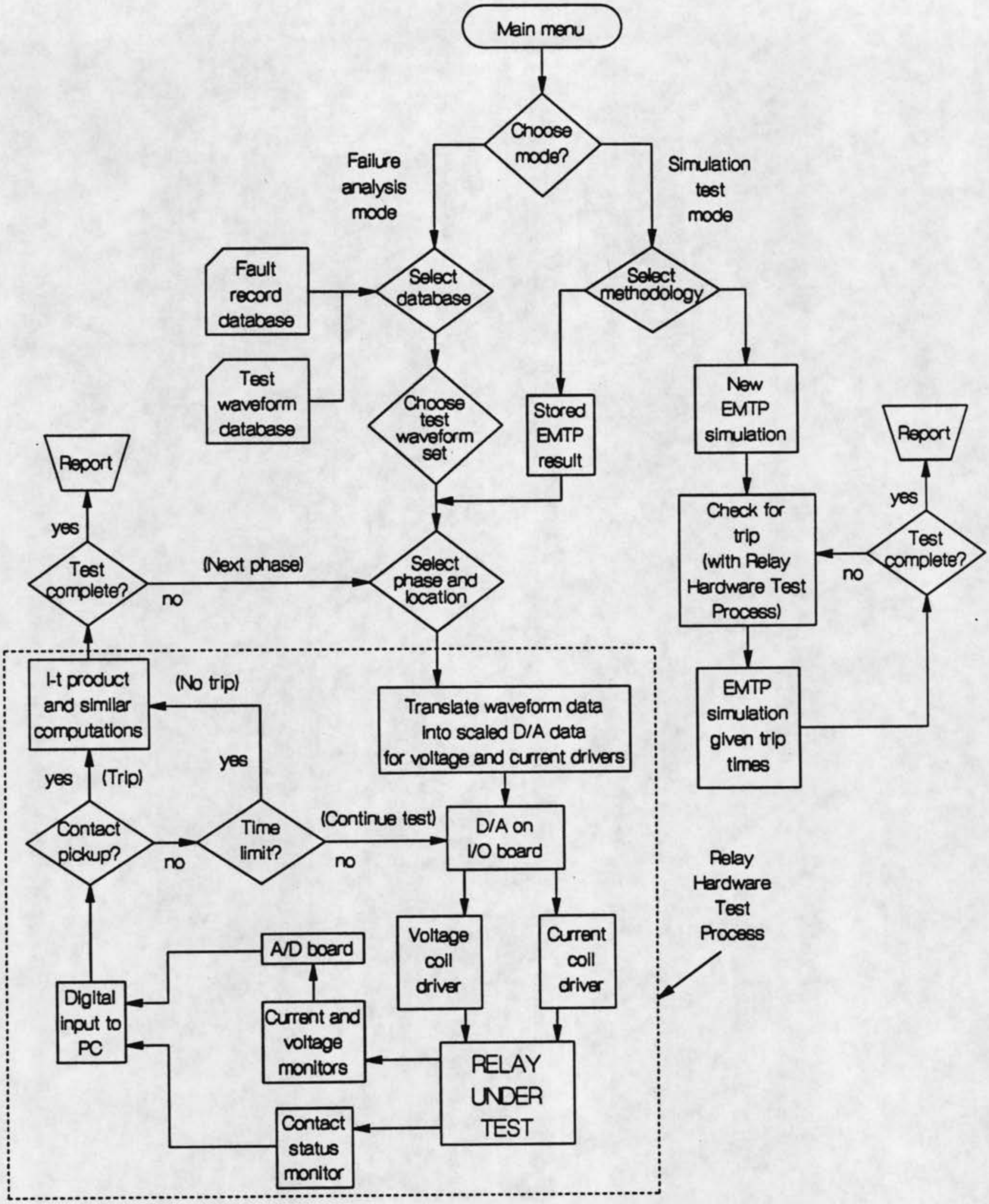

Figure 16. Simplified flowchart of software.

trace in 92 ms, on an 80286 PC. The data consisted of about two full current cycles and more than 1000 points. The output rate exceeds 10000 samples per second on a relatively slow computer. Even highly distorted power waveforms can be tracked given this rate.

Five copies of the waveform were presented to the Techron amplifier in quick succession to form a 10 cycle 60 Hz burst signal. Figure 17 shows this burst imposed on a

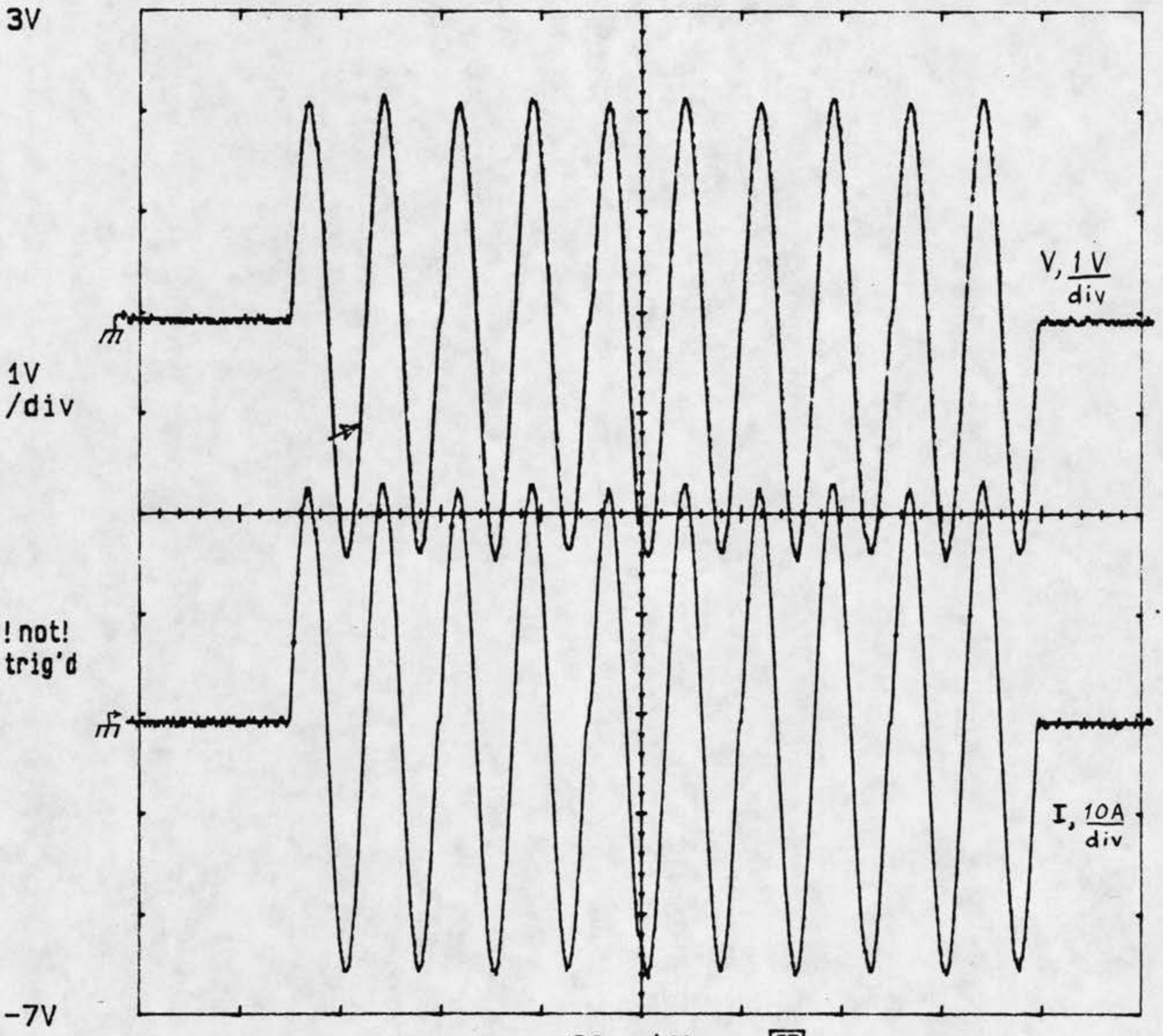

Figure 17. Ten cycle 60 Hz burst test into 1.2 Ω load.

1.2 Ω resistive load by the amplifier. The upper trace is the analog output from the computer, at 1 V/div. The lower trace is the amplifier output current, at 10 A/div. The high fidelity of the amplifier is demonstrated by the faithful reproduction of the input waveform — even small kinks during which the communication program was preparing to repeat a loop. At a higher gain setting, the amplifier could drive the load up to 28 A peak for this burst signal.

The PC and Techron amplifier combination was used to test the operation of a Westinghouse Type CO overcurrent relay, supplied by Commonwealth Edison. Figure 18 shows a single-pulse fault test of the instantaneous trip current coil. The waveform is a highly distorted fault test case. The top trace is the analog output from the PC, and the bottom trace is the actual coil current. In this case, the waveform caused the trip mechanism to fire. The I/O board digital inputs would permit precise timing of the trip delay.

A more conventional time-current test is represented in Figure 19. The PC can easily repeat a waveform sequence for a specified time. In this case, the EMTP waveform was applied repeatedly for five seconds. The figure shows only the last few cycles of the test. The relay was set in its 4 A tap position. In this case, the relay disk moved, but did not close the contacts within the five second span of the test. An important result from this test is that the amplifier can provide high output currents (here 22 A peak into a 4 Ω burden) for several seconds at a time.

Conclusion

Power audio amplifiers offer a straightforward way to drive relay coils for testing purposes. Amplifiers available today can produce enough current to drive a coil well into saturation. The growing power of personal computers makes it feasible to perform interactive simulations with programs such as EMTP, then take simulation results and use them as amplifier inputs. In this way, PC-based relay test systems can be designed and constructed.

There are few limits to the capabilities of a test system with this architecture. Distorted waveforms with frequency content up to several kilohertz can be used to drive relay

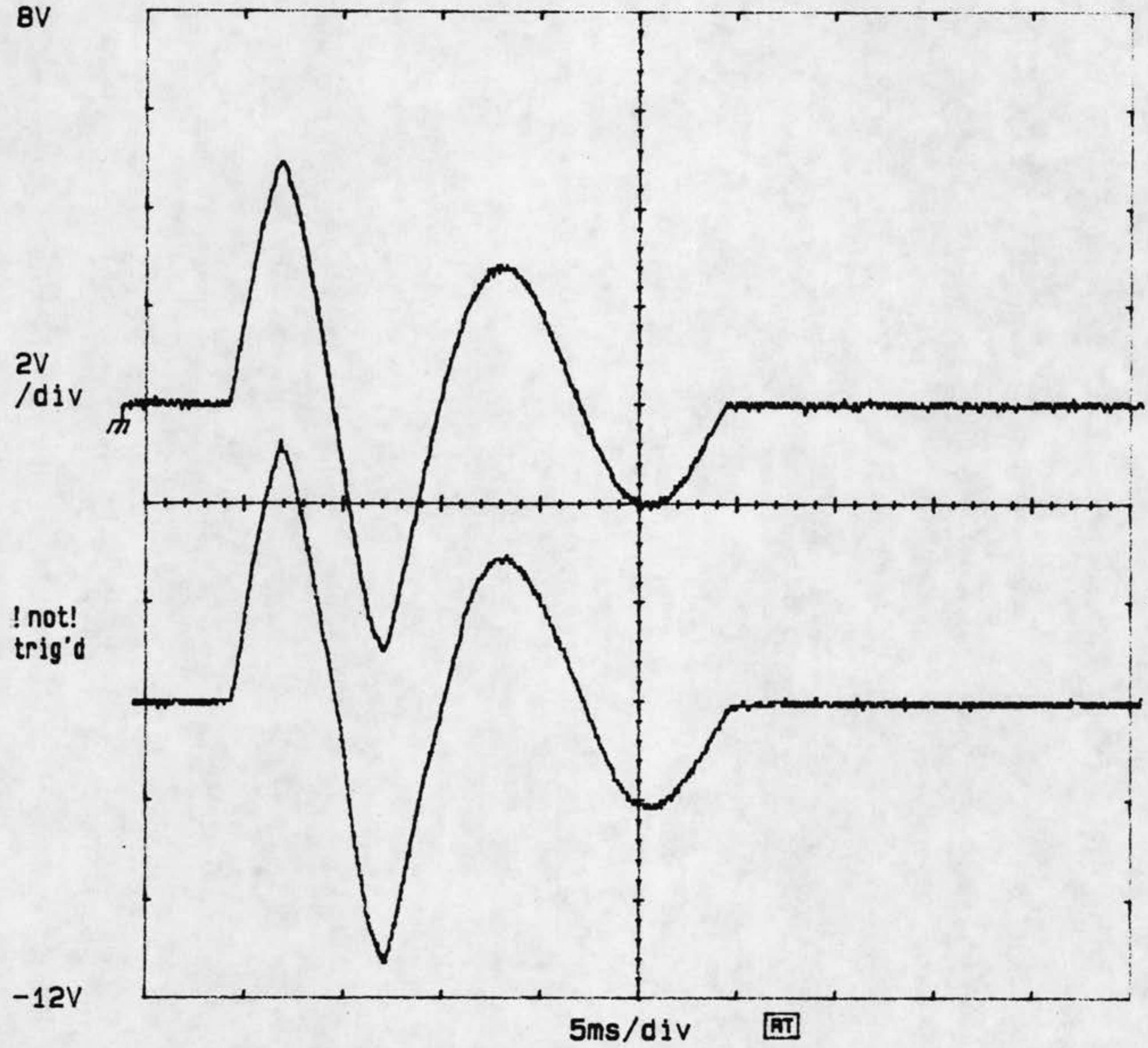

Figure 18. One cycle test of Westinghouse Type CO relay instantaneous trip coil.
Top trace: Computer D/A output, 2 V/div.
Bottom trace: Coil current, 10 A/div.

coils even with a rather slow PC. Three-phase relays require additional amplifiers, but can be controlled with available PC interface cards. It is possible to test at higher VA levels by using parallel and series combinations of amplifiers. The system design shifts most of the effort into software, which greatly enhances the flexibility.

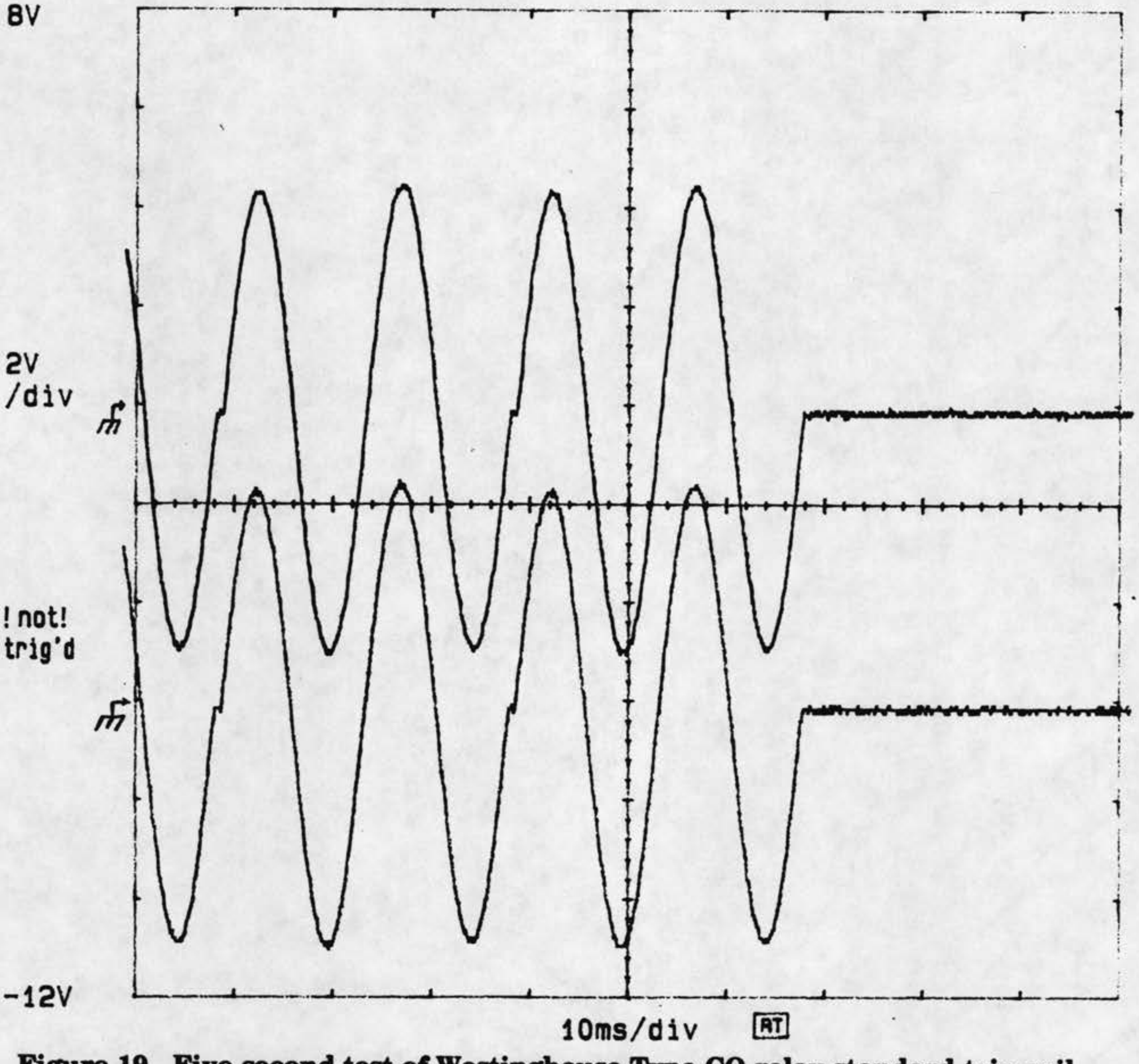

Figure 19. Five second test of Westinghouse Type CO relay standard trip coil.
Top trace: Computer D/A output, 2 V/div, last four cycles only.
Bottom trace: Coil current, 10 A/div, last four cycles only.

A software architecture was proposed in Figure 16. The arrangement would support direct tests of a relay based on stored fault information or specific test waveforms. It would also support tests based on simulated fault data. Two modules in the software system have been tested: a module to translate raw waveform data into the form necessary for PC analog output, and a module to write data to the analog port.

The basic functions of the system have been demonstrated with a conventional overcurrent relay. A key remaining issue is the need for a user-friendly, interactive program to operate the system.

Equipment costs are minimal. The system at present consists of a PC valued at no more than $500, an amplifier with cost of $3500, a $350 plug-in digital/analog I/O board, and an additional A/D circuit board.

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[15] P. Erath and R. Loretz, "A modern approach to digital fault simulation," *Autotestcon*, (IEEE cat. no. 89CH2568-4) 1989, pp. 118-123.

[16] C. W. Barnett, *et al*, "Summary of the special publication 'Application of fault and disturbance recording devices for protective system analysis,'" *IEEE Trans. Power Delivery*, vol. 4, no. 3, July 1989, pp. 1625-1630.

[17] S. A. Ellerthorpe, "A research laboratory for testing of real-time control schemes for induction motor drives." M.S. thesis, University of Illinois, Urbana, IL, 1992, pp. 142-149.

Appendix

A. Computer programs

1. EMTP card set for phase A line-to-ground fault simulation.

2. CONVD2A.BAS, a BASIC program to translate EMTP results in preparation for output to the PC I/O card.

3. SEND_D2A.BAS, a BASIC program to ship data out to the PC I/O card repeatedly. The output rate on a 10 MHz 80286 machine is about 10000 samples per second.

B. Circuits — AD7874 circuit arrangement for sensing of two current and two voltage channels [17].

C. Attachments -- specification summaries of CIO-DDA06 and Techron 7570.

A. Computer Programs

1. EMTP card set for phase A line-to-ground fault simulation.

```
BEGIN NEW DATA CASE
C ... Raymond Klump   October 10, 1992
C ... V_A2G.DAT -  Voltages at Remote and Source Buses For A-to-Grd. Fault
C ... Model is of a 138 kV, 3-Phase System.  Source Bus is 20 kA.  Remote end
C ... is terminated by a 3-Phase, 10 MVA transformer.  The modeling of all
C ... system components is discussed to great detail in the lab notebook.
C ... The quantities of interest are the voltages and currents experienced at
C ... the relays as a function of time for an A-Phase to Ground fault.
C ****************************************************************************
C ............................ MISCELLANEOUS CARDS............................
C ****************************************************************************

  50.E-6  50.E-3       0.        0.  1.E-17
    1000       1       0       1       1       0       0       1
C ****************************************************************************
C ...............................LOAD CARDS...................................
C ****************************************************************************
C ... SOURCE IMPEDANCE
     A1    A2                  0.265 10.53
     B1    B2                  0.265 10.53
     C1    C2                  0.265 10.53
C ... TRANSFORMER INDUCTANCE
     A5    A6                        404.5
     B5    B6                        404.5
     C5    C6                        404.5
C ... LOAD RESISTANCE
     A6                        3809.
     B6                        3809.
     C6                        3809.
C ... LOAD INDUCTANCE
     A6                              6062.
     B6                              6062.
     C6                              6062.
C ... 148KM 795MCM ACSR TRANSMISSION LINE CONNECTING SOURCE TO XFMR BUS
-1   A3    A4                  2.6E-44.2E-35.1E-632.2E3

-2   B3    B4                  8.6E-51.3E-39.1E-632.2E3
-3   C3    C4

C ****************************************************************************
C .............................SWITCH CARDS...................................
C ****************************************************************************
C ... Relays are present at the source and the load buses on each phase.
C ... Initially, we shall assume that they remain closed for the duration of
C ... the study.  Later, these shall attempt to open at the first current zero.
     A2    A3    -1.000      1.000
     B2    B3    -1.000      1.000
     C2    C3    -1.000      1.000
     A4    A5    -1.000      1.000
     B4    B5    -1.000      1.000
     C4    C5    -1.000      1.000
C ... At time of A-Phase Max Voltage, A will be shorted to ground at source.
     A3        16.667E-3     1.000
```

```
C ***************************************************************************
C ..............................SOURCE CARDS..........  .........................
C ***************************************************************************
C ... THE CAP BANK AND REMOTE BUSES ARE FED OFF A 138KV, 60HZ SYSTEM
14    A1     112.68E3          60.        0.         0                      -1.0         1.0
14    B1     112.68E3          60.     -120.         0                      -1.0         1.0
14    C1     112.68E3          60.     -240.         0                      -1.0         1.0
C ***************************************************************************
C .......................NODE VOLTAGE OUTPUT REQUESTS.............................
C ***************************************************************************
C ... REQUEST NODE VOLTAGES AT CAP BANK AND REMOTE XFMR BUSES
      A3    B3    C3    A5    B5    C5
```

2. *CONVD2A.BAS, a BASIC program to translate EMTP results in preparation for output to the PC I/O card.*

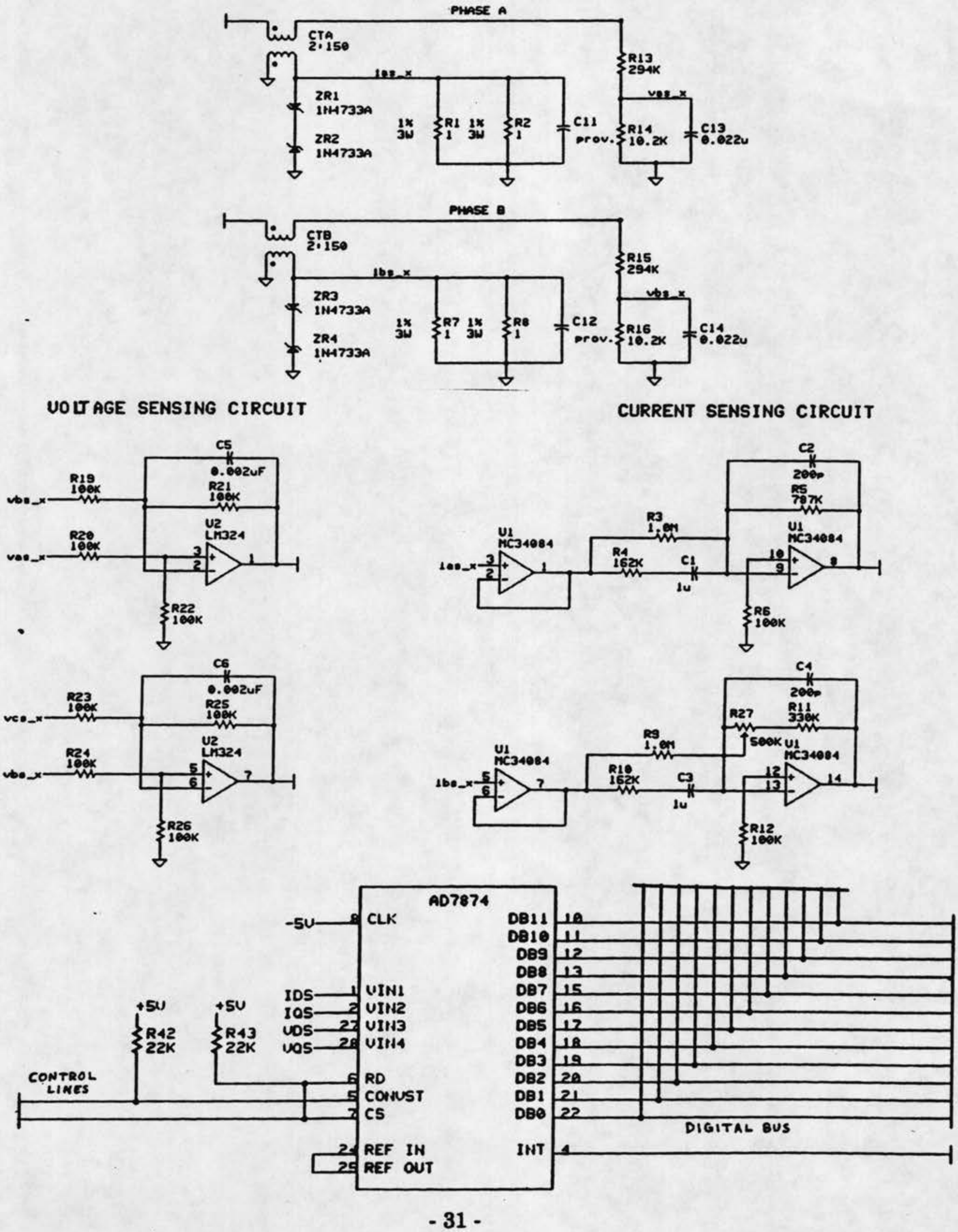
```
INPUT "Enter Name of File to Convert to D/A Board Format: ", file$
OPEN "c:\com_ed\" + file$ FOR INPUT AS #1

'Strip off header
maxim = 0
FOR X = 1 TO 9
  LINE INPUT #1, LINE$
NEXT X
LINE INPUT #1, LINE$

' First, find maximum of the A-phase Source Quantity
DO WHILE NOT EOF(1)
   IF ABS(VAL(MID$(LINE$, 10, 16))) > maxim THEN
      maxim = ABS(VAL(MID$(LINE$, 10, 16)))
   END IF
   LINE INPUT #1, LINE$
LOOP

CLOSE #1
OPEN file$ FOR INPUT AS #1
INPUT "Enter desired name of output file with a d2a extension: ", outfile$
OPEN "c:\com_ed\" + outfile$ FOR OUTPUT AS #2

' Convert Emtp data to a format which is readable by board.
FOR X = 1 TO 9                                    'Again strip header.
  LINE INPUT #1, LINE$
NEXT X
LINE INPUT #1, LINE$

'Convert and output
DO WHILE NOT EOF(1)
   daval% = INT((VAL(MID$(LINE$, 10, 16)) + maxim) / (2 * maxim) * 4095)
   IF daval% < 0 THEN daval% = 0
   PRINT #2, daval%
   LINE INPUT #1, LINE$
LOOP
CLOSE #1
CLOSE #2
END
```

3. *SEND_D2A.BAS, a BASIC program to ship data out to the PC I/O card repeatedly. The output rate on a 10 MHz 80286 machine is about 10000 samples per second.*

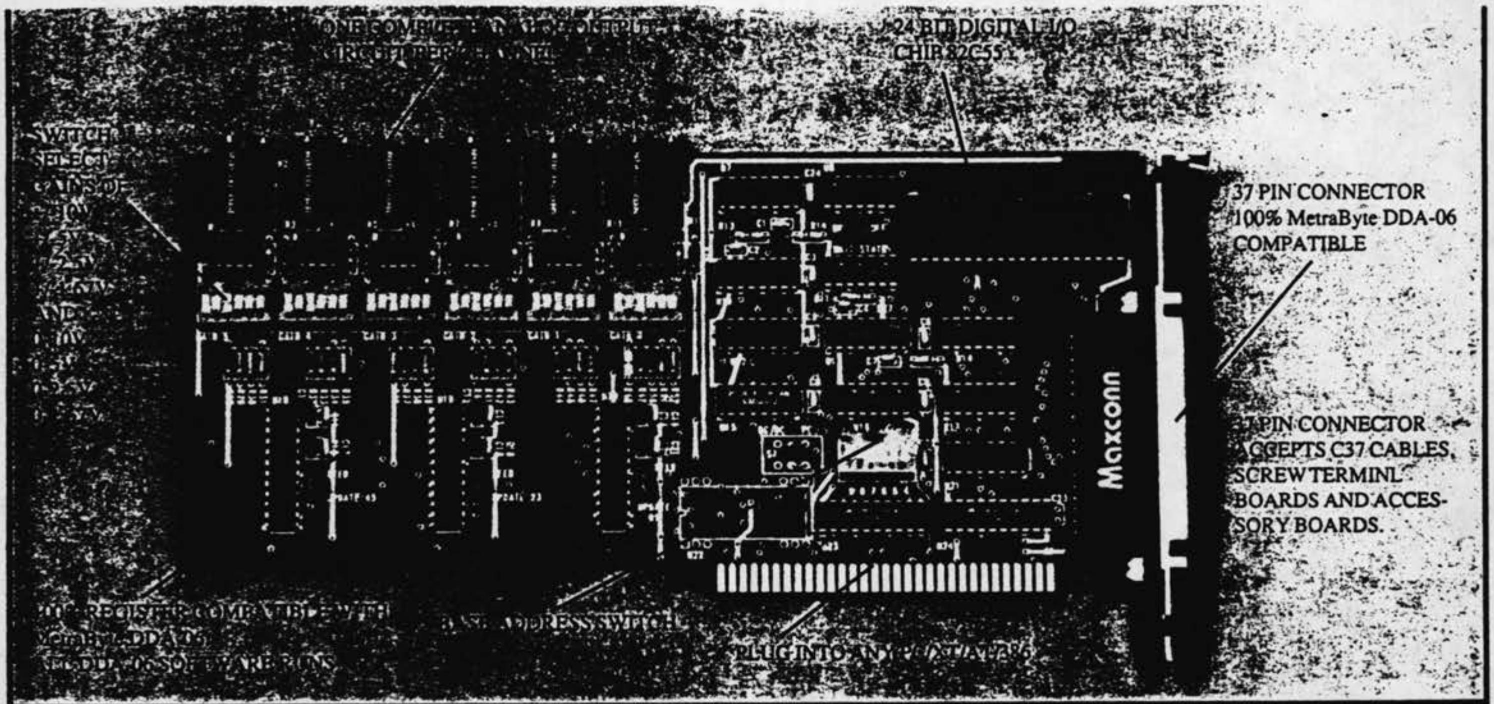
```
' Now you must enter the name of the file you created using conva2d.bas
INPUT "Enter name of converted EMTP file with .d2a extension: ", d2a$

' First, zero out the data (zero for the DAC output is 2048, center scale).
DIM datlo%(1024), dathi%(1024)
FOR i = 0 TO 1024
      datlo%(i) = 2048 AND &HFF
      dathi%(i) = 2048 \ 256
NEXT i

i = 0

OPEN d2a$ + ".d2a" FOR INPUT AS #1

' Read all the data into an array, formatting into bytes as you go.
WHILE NOT EOF(1)
reread:
INPUT #1, dat%
IF dat% < 0 OR dat% > 4095 THEN GOTO reread
datlo%(i) = dat% AND &HFF
dathi%(i) = (dat% - datlo%(i)) \ 256  'CONSTRUCT HIGH BYTE OF DATA
i = i + 1
WEND

CLOSE #1

' Print the number of data points
II = i - 1
PRINT II; " points in waveform."

' BA% is the decimal representation of the base DAC address value
BA% = 784
CH% = 5
Loadr% = BA% + CH% * 2
Hiadr% = BA% + CH% * 2 + 1

' Channel number is set to 5, and the data value to be sent is to come from
' the input file.

' For the actual test, a certain number of repetitions might be needed.
PRINT "Is there a specific number of sequences? (0 if not)"
INPUT nseq0
nseq = nseq0

' Now, send the data.  It is fastest to just send it brute force.  A loop
'       of any kind will slow the system down.  Of course, an efficient
'       assembly routine would work well, too.
```

```
Reloop:
      OUT Loadr%, datlo%(0):          OUT Hiadr%, dathi%(0)
      OUT Loadr%, datlo%(1):          OUT Hiadr%, dathi%(1)
      OUT Loadr%, datlo%(2):          OUT Hiadr%, dathi%(2)
      OUT Loadr%, datlo%(3):          OUT Hiadr%, dathi%(3)
      OUT Loadr%, datlo%(4):          OUT Hiadr%, dathi%(4)
      OUT Loadr%, datlo%(5):          OUT Hiadr%, dathi%(5)
      OUT Loadr%, datlo%(6):          OUT Hiadr%, dathi%(6)
      OUT Loadr%, datlo%(7):          OUT Hiadr%, dathi%(7)
      OUT Loadr%, datlo%(8):          OUT Hiadr%, dathi%(8)
      OUT Loadr%, datlo%(9):          OUT Hiadr%, dathi%(9)
      OUT Loadr%, datlo%(10):         OUT Hiadr%, dathi%(10)
.
.
.
' And so on, through 1024.
.
.
.
      OUT Loadr%, datlo%(1014):       OUT Hiadr%, dathi%(1014)
      OUT Loadr%, datlo%(1015):       OUT Hiadr%, dathi%(1015)
      OUT Loadr%, datlo%(1016):       OUT Hiadr%, dathi%(1016)
      OUT Loadr%, datlo%(1017):       OUT Hiadr%, dathi%(1017)
      OUT Loadr%, datlo%(1018):       OUT Hiadr%, dathi%(1018)
      OUT Loadr%, datlo%(1019):       OUT Hiadr%, dathi%(1019)
      OUT Loadr%, datlo%(1020):       OUT Hiadr%, dathi%(1020)
      OUT Loadr%, datlo%(1021):       OUT Hiadr%, dathi%(1021)
      OUT Loadr%, datlo%(1022):       OUT Hiadr%, dathi%(1022)
      OUT Loadr%, datlo%(1023):       OUT Hiadr%, dathi%(1023)
      OUT Loadr%, datlo%(1024):       OUT Hiadr%, dathi%(1024)

' Now, check.  If the requested number of reps is complete, prompt for
'       a response.  If the user hit a key (or if a relay pickup has
'       generated an interrupt) prompt for information.
nseq = nseq - 1

k = k + 1
IF INKEY$ <> "" OR nseq = 0 THEN
      IF nseq = 0 THEN PRINT "Sequence number completed."
      PRINT "Do I see keyboard input (s to stop, more to do again)?"
      INPUT a$
          IF a$ = "" then a$ = "m"
      IF LEFT$(a$, 1) <> "m" AND LEFT$(a$, 1) <> "M" THEN PRINT k: STOP
      nseq = nseq0
END IF

' Send the data again if requested.
GOTO Reloop
END
```

B. Circuits — AD7874 Circuit Arrangement for Sensing of Two Current and Two Voltage Channels [17].



C. Attachments -- Specification Summaries of CIO-DDA06 and Techron 7570.



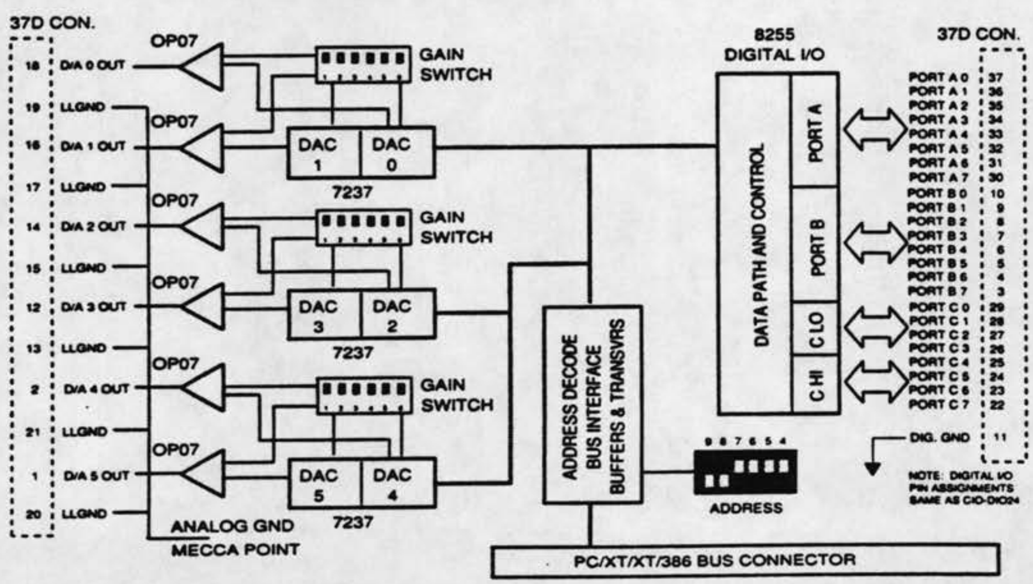
DESCRIPTION

The CIO-DDA06 analog output and digital I/O board is designed to be 100% compatible with MetraByte's popular DDA-06, with the exception of current output, at a lower cost.

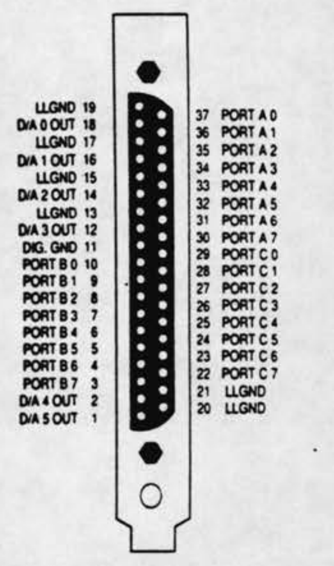
Installed in any IBM PC/XT/AT/PS30 or compatible computer the CIO-DDA06 turns your personal computer into a analog and digital control station suitable for proportional valve control, high voltage AC and DC contact monitoring and on/off control. The CIO-DDA06 is two boards in one; a 24 bit ditital input/output board that is PIO-12 compatible and a 6 channel analog output board. The 37 pin D connector's 24 digital I/O pins are assigned identically to a PIO-12 (or CIO-DIO24). The analog outputs occupy the remaining pins. This means that accessories such as the SSR-RACK24 just plug right in!

The CIO-DDA06 is supplied with a complete user's manual, calibration tools, BASIC CALL, calibration software and GW and Quick Basic example programs.

CIO-DDA06 BLOCK DIAGRAM



CIO-DDA06 CONNECTOR

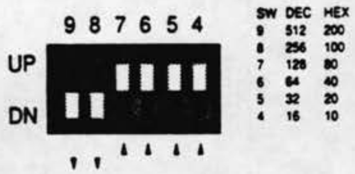


BASE ADDRESS SWITCH

The CIO-DDA06 occupies 16 consecutive I/O addresses. The first, or Base Address, is set by a bank of switches in a DIP switch on the board. It is possible to set the base address of the CIO-DDA06 anywhere within the range 0 to 3FF Hex. Because of this flexibility, multiple CIO-DDA06 boards, or other I/O boards, may be used in the same PC.

BASE ADDRESS SWITCH

SETTINGS SHOWN - 300 HEX, 768 DECIMAL



A/D SPECIFICATIONS — 12 BIT

Channels	6 Voltage Output
Resolution	12 Bit, 1 part in 4095
D/A Type	Dual DAC, AD7237
Latches	Double buffered/Sim. Update
Linearity	+/- 1/2 Bit
Monotonicity	+/- 1/2 Bit
Temperature drift	1ppM Typ., 3ppM Max @ 0V 15ppm Typ., 30ppM max @ FS
Load Current	+/-5mA Max
Short Circuit Current	40mA Max
Output Resistance	<0.1 ohm
Settling Time + FS 0.01%	3uS Typical, 5uS Max
Settling Time -FS 0.01%	5uS Typical, 10uS

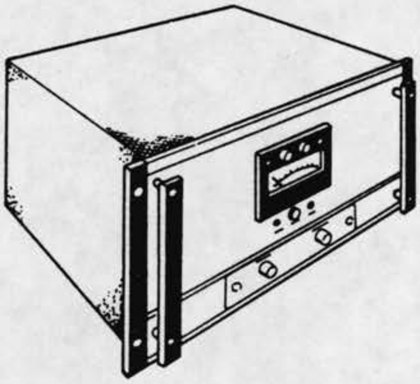
OUTPUT RANGES

Bipolar Range (+/-V)	Unipolar Range (V)
10	10
5	5
2.5	2.5
1.67	1.67

DIGITAL SPECIFICATIONS — TTL

I/O Ports	2 Eight Bit, 2 Four Bit
Total Bits	24
Output High	2.4V Min @ -200uA
Output Low	0.5V Max @ 2.5 mA
Input High	2.0V Min, 7.0V Max
Input Low	-0.5V Min, 0.8V Max

TECHRON



MODEL 7570
CONTROLLED CURRENT AMPLIFIER
SPECIFICATIONS

TECHRON'S 7570 Controlled Current Amplifier is built on the same advanced power amplifier technology as the TECHRON 7560. By building in current control circuitry, TECHRON has added the capability to control the load current of the amplifier as the programmed output-variable and not the output voltage. This controlled current mode is useful in areas where the field produced by a coil needs to be proportional to coil current and not voltage.

CONTROLS

Front Panel: Controlled Current/Constant Voltage toggle switch and Input attenuator.

Rear Panel: Turn on delay slide switch.

CONNECTORS

Input: Three screw barrier block, BNC for optional input.

Output: Heavy duty, two screw barrier block or five way binding posts.

Current Monitor: 1/4", three conductor phone plug.

Interlock: 11 pin "Octal" style socket, mating connector supplied.

ELECTRICAL

Peak Voltage and Current: 100 volts DC at 20 amps, load dependent. 120 volts unloaded.*

Input Sensitivity: .1Volt/Ampere

Input Impedance: 20kΩ, differential.

Input Common Mode Rejection Ratio: Greater than 70 dB.

Input Common Mode Rejection Range: + 11 Volts.

Current Monitor Scale: 2Volt/Ampere Differential

Current Monitor Impedance: Differential, 600 Ω. Single ended, 300 Ω.

EXPANSION

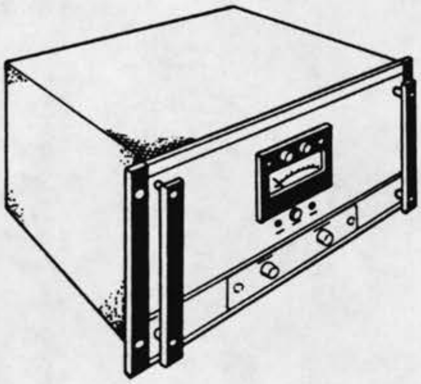
TECHRON 7570 controlled current amplifiers may be placed in parallel or push pull with one or more TECHRON 7560s for higher current or voltage applications

* The electrical specifications that appear on the 7560 data sheet apply to the power stage of the 7570. These voltage mode specifications will bound the actual controlled current performance with a reactive load.

TECHRON

1718 W. Mishawaka Road
Elkhart, Indiana 46517
(219) 294-8300

TECHRON®

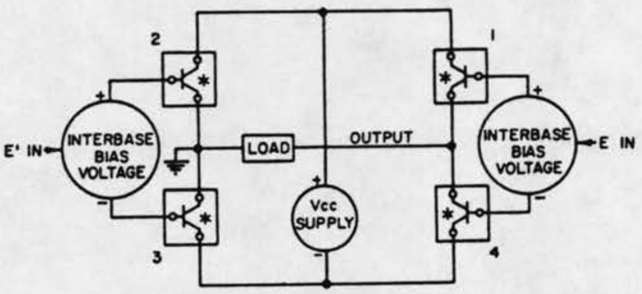


MODEL 7560

POWER SUPPLY AMPLIFIER SPECIFICATIONS

TECHRON's 7560 Power Supply Amplifier delivers accurate high power levels with complete self-protection for dependable operation. At frequencies from DC to 40KHz, 1,000 watts continuous average output into 4 ohms is typical, with extremely low distortion and noise.

The Patented Bridge Circuitry in the 7560 effectively doubles the available output voltage without exposing output transistors to excessive voltages. In addition, the patented AB+B mode of operation means that quiescent current is carried by the driver transistors only, calling on the output section exactly as necessary for precise high power output.



∗ COMPOSITE TRANSISTOR

The SPACE Controller (Signal Programmed Automatic Current Executor) circuit acts as a signal-variable current limiter at most frequencies, and as a Voltage/Current limiter at low frequencies and DC, offering comprehensive protection against amplifier damage, no matter what the input or output demands may be.

The Interlock Circuit allows multiple 7560's to operate together for even higher power levels without any possibility of amplifier damage due to unsynchronized starting and stopping. The interlock also allows external start/stop control of an entire amplifier system.

Modular Construction permits rapid servicing and accurate parts replacement. Output modules also enable thorough, even cooling for minimum stress on electronic components.

TECHRON engineering supports the 7560 with constant attention to user needs, design assistance for special installations, and a wealth of technical know-how to handle new or unusual applications for the 7560.

The TECHRON 7560 Power Supply Amplifier is a proven, yet innovative system that's tough enough for industrial environments, dependable enough for medical uses, and accurate to laboratory standards.

TECHRON®

1718 W. Mishawaka Road

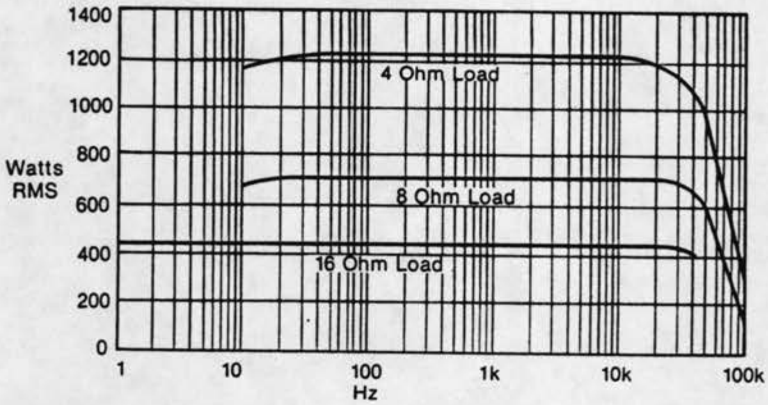
Elkhart, Indiana 46517

(219) 294-8300

TECHRON®

	7560 (Single Unit)	DUAL 7560's (Bridged)*
POWER RESPONSE	**8 ohm load:** DC-45KHz at 600 W Continuous average output power with no more than .05% THD (Total Harmonic Distortion) **4 ohm load:** DC-40KHz at 1KW continuous average output power with no more than .07% THD (Total Harmonic Distortion)	**8 OHM LOAD:** +1, —0dB, DC-40KHz at 2KW continuous average output power with no more than .1% THD (Total Harmonic Distortion) **16 ohm load:** +1, —0dB, DC-45KHz at 1.2KW continuous average output power with no more than .07% THD (Total Harmonic Distortion)
POWER AT CLIP POINT: (LESS THAN .01% THD at 1 KHz)	**8 ohm load:** Typically 750W **4 ohm load:** Typically 1350W	**8 ohm load:** Typically, 2.7KW **16 ohm load:** Typically, 1.5KW
DC OUTPUT	Typically 20A maximum (supply fuse limited) at 100V or 2KVA	Typically 20A maximum (supply fuse limited) at 200V or 4KVA
FREQUENCY RESPONSE (8 ohm load)	**DC-20KHz:** +/−.1dB at 1W **DC-100KHz:** +/−1dB at 1W **10Hz-100KHz:** +/−1dB at 1W, AC coupled via standard input plug-in	**DC-20KHz:** +/−.2dB at 1W **DC-50KHz:** +/−1dB at 1W
PHASE RESPONSE	+0, −15° DC-20KHz at 1W into 8 ohms	+0, − 20°, DC-20KHz at 1W into 8 ohms
SLEW RATE	32V/usec	64V/usec
I.M. DISTORTION (60Hz-7KHz 4:1)	Less than .05% from .01W to 600W (peak equivalent to a single sinusoid, rms) into 8 ohms. Less than .01% at 600W into 8 ohms or 1200W into 4 ohms.	Less than .1% from 10mW to 2KW (peak equivalent to a single sinusoid, rms into 8 ohms)
HARMONIC DISTORTION (TRUE RMS MEASURE)	Less than .05% from DC-45KHz at 600W into 8 ohms. Less than .001% from 20Hz-400Hz and increasing linearly to .05% at 600W into 8 ohms.	Less than .05% from DC-10KHz at 2KW into 8 ohms.
OUTPUT IMPEDANCE	5 mohms in series with 1.25uH which are together shunted by 2.7 ohms in parallel with 0.1uF	20 mohms in series with 4uH
LOAD IMPEDANCE	Normally, 4 ohms or greater; maximum continuous sinusoidal output power at 2.5 ohms. Lower impedance affects only maximum power. The 7560 will drive a completely reactive load with no harm to the amplifier. Highly inductive loads may require external compensation to avoid oscillations.	(Balanced Output): Primarily used at 8 ohms or greater; maximum continuous sinusoidal output power at 5 ohms. Lower impedance affects only maximum power.

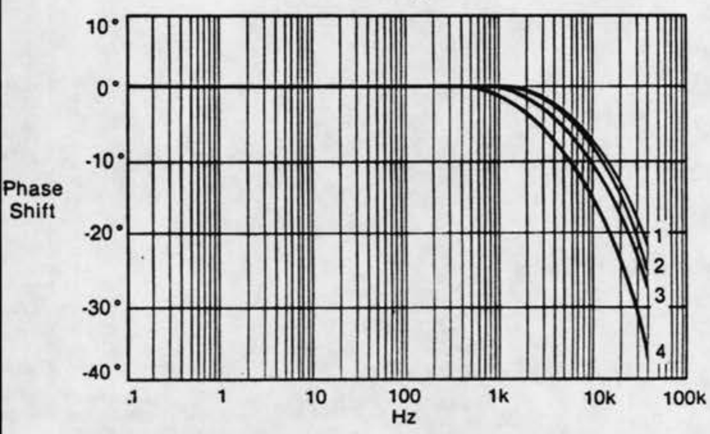
Typical Power Output



	7560 (Single Unit)	DUAL 7560's (Bridged)*
INPUT GAIN	20 +/−1% (26dB) at standard input, input attenuator fully CW (1 +/−1% at interlock connector input)	40 +/−1% for (32dB) at standard input with input attenuator fully CW
INPUT SENSITIVITY	3.45 VC rms +/−1% for 600W into 8 ohms	3.6V rms +/−1% for 2KW rms into 8 ohms
INPUT IMPEDANCE	25K +/−30% with standard input. 44.76K +/−5% at interlock connector input.	25K +/− 30% with standard input
HUM AND NOISE (20Hz-20KHz)	100dB below 600W into 8 ohms. Typically 107dB.	96dB below 2KW into 8 ohms. Typically 104dB.
DC DRIFT AT OUTPUT	Typically less than 100uV/°C with all inputs grounded	Typically less than 200uV/°C with inputs grounded
POWER REQUIREMENTS	50-60Hz AC, single phase, with adjustable taps for 100, 120, 200, 220 and 240V +/−10% operation	50-60Hz AC with adjustable taps for 100, 120, 200, 220 and 240V +/−10% operation
POWER DRAW	116W or less on idle; 1KW at 600W output into 8 ohms	232W or less on idle, 3.8KW at 2KW output into 8 ohms
COOLING CAPACITY	Forced air cooling with eight high efficiency heatsinks can dissipate 1900W with 25°C intake air at 1 atmosphere. (Dissipation downgrades to zero at 75°C.) Dual fans with washable intake filters force air through heatsinks and out both the top and bottom of the amplifier.	
TURN-ON DELAY	Switch-selected for instant on or 4-5 seconds of delay at turn-on	
LOW FREQUENCY LOAD PROTECTION	Switch-selected, producing shutdown of the high voltage power supply at DC outputs greater than 6V or low frequency outputs greater than 600W at 20 Hz and 8 ohms.	
OUTPUT TRANSISTOR PROTECTION	Short, mismatch, and open-circuit protection; electronic protection operates without thumps or shutdown.	
MAXIMUM AC CURRENT DRAW	20 Amps	
OPERATING ENVIRONMENT	0-25°C, non-condensing at 90% or less humidity	
INTERLOCK	11-pin "octal" type socket provides interlock function to allow simultaneous start/stop for multiple 7560's driving a common load.	

*These specifications are for two Model 7560 amplifiers joined into a bridge by cable option 75D01. Other combinations of multiple 7560 amplifiers can be constructed. Consult the factory for design assistance.

Phase Response



Notes:

1. Curve 1 — Open Ckt and 16 Ohm Load
2. Curve 2 — 8 Ohm Load
3. Curve 3 — 4 Ohm Load
4. Curve 4 — Input Atten. Set to -6 : 8 Ohm Load (Worst Case)
5. Effective Signal Delay Td = 1.5 uSEC — Open
   = 1.6 uSEC — 16 Ohms
   = 1.7 uSEC — 8 Ohms
   = 1.9 uSEC — 4 Ohms
   = 2.6 uSEC — Worst Case
6. Output 2.828 Volts All Loads

GENERAL SPECIFICATIONS

Protection circuitry in the 7560 prevents damage due to high line voltage, overtemperature, RF burnouts, input overload, excessive output demand, mismatched loads, shorted loads, and internal malfunction.

Displays:

Power on: red neon indicator, plus green mechanical indicator in power switch to help verify power connection
Standby: amber neon indicator

Controls:

Push-push power switch

AC/DC coupling switch
Input Attenuator Pot
(with standard input plug-in)

Low Frequency Protect Switch
Turn-on Delay Switch
(rear panel)

Input Plug-ins:

The 7560's input plug-ins provide a wide range of input flexibility.

Standard Input Card:
AC/DC Coupling Switch
Input Attenuator
Universal PC board for user-constructed input modifications

Several other custom input cards are available from TECHRON.

Still others can be built by users from TECHRON designs, or from custom designs.

Input options include differential inputs, filters, oscillators, servo amplifiers, remote DC gain controls, compressors, digital controllers, etc. Regulated +/− 15VDC supplies are provided, with the maximum total available current of the supplies limited to 50ma (25ma with optional meter display module). The delay mode of amplifier operation may be programmed from the plug-in.

Connectors:

Standard Input: BNC jack

Special Input: 3-terminal barrier strip can route input to input card for special input modifications.

Output: Two-terminal barrier strip for permanent connections; color coded binding posts on standard 3/4" centers for monitoring or temporary connections

AC Line: Three-wire 20A, 120V male connector with 5-foot cable

Interlock: 11-pin "octal" type socket provides interlock function to allow simultaneous start/stop for multiple 7560's driving a common load.

Construction:

Aluminum chassis with 1/4" thick front panel reinforced with steel to retain the power transformers, 1/8" aluminum side panels. Heavy duty handles on front for easy transport. Plug-in circuit boards.

Dimensions:

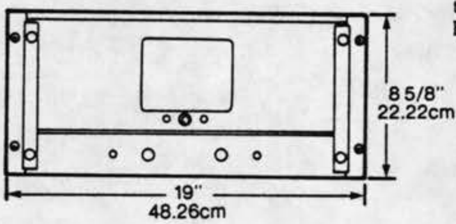
19" (48.26cm) standard rack mount, 8¾" (22.22cm) height, 16½" (41.91cm) behind mounting surface, handles extend 2" in front of mounting surface. Center of gravity is nearly centered at 5" behind the mounting surface.

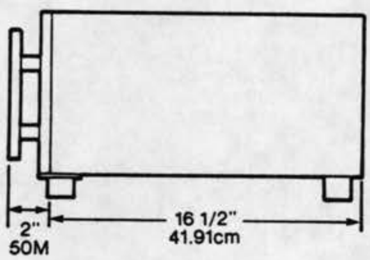
Weight:

92 pounds (41.7kg) net weight

Finish:

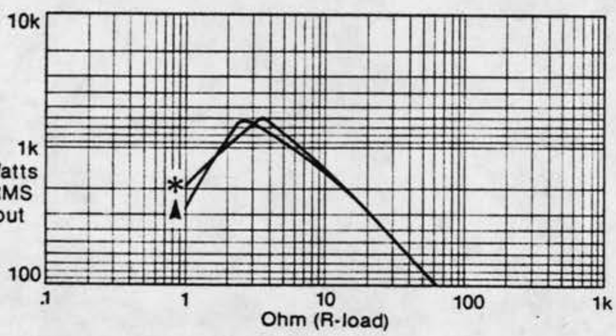
Two tone front panel coated with durable textured polyurethane. The front panel is tan; handles and end bars dark brown. Black painted aluminum chassis and covers.





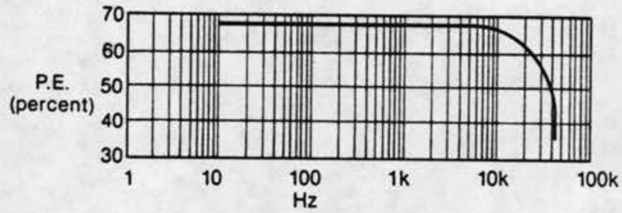
Mounting Dimensions

Output vs. R (Load) at 1KHz

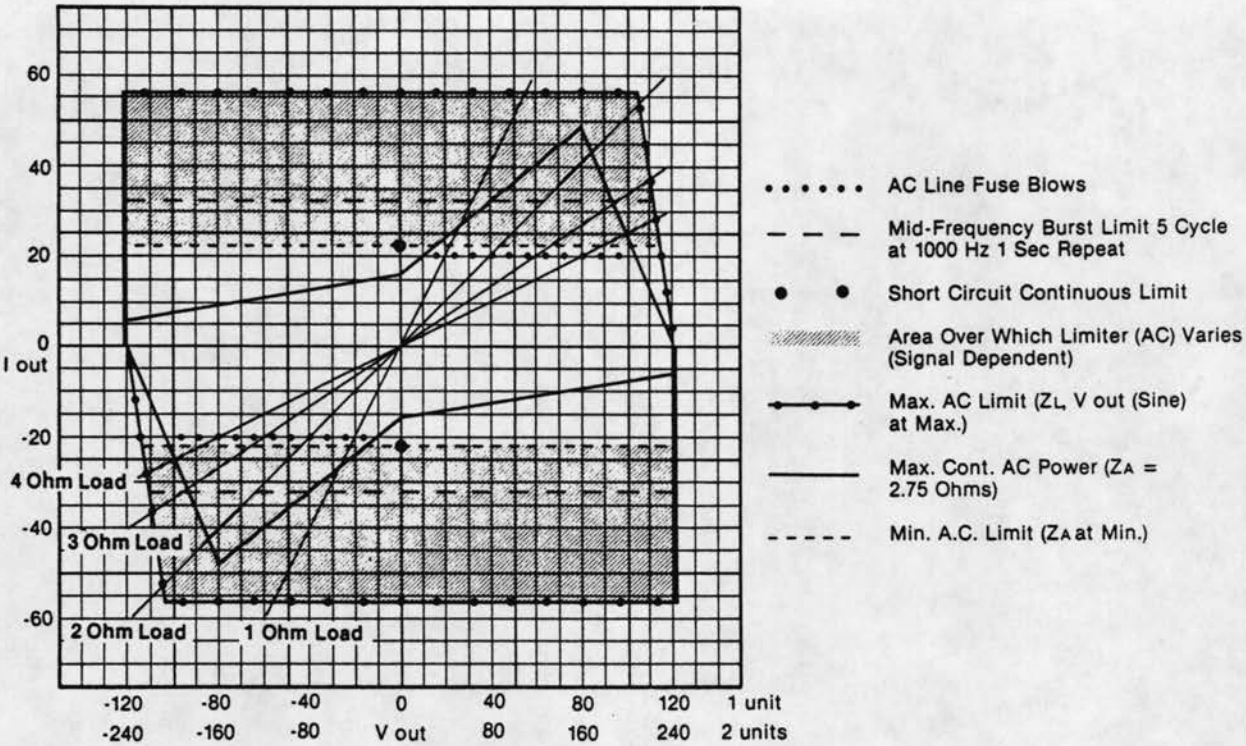


NOTES:
1. ✻—Continuous
2. ▲—Tone Burst

Typical Power Efficiency: 120 VAC-Driven to Maximum Undistorted Level at 8 Ohms



THE V-I GRAPH



The unique protection circuitry of the TECHRON 7560 enables it to operate at or near its limits of performance as easily and safely as it would in less demanding situations. The V-I plot helps users of the 7560 to predict amplifier performance with varied loads and power demands.

Users of the TECHRON 7560 can plot load characteristics on the V-I Graph to be sure of accurate, dependable operation in each application. Experienced users will be able to plot load characteristics on the V-I Graph for an immediate assessment of the 7560's capabilities in each intended use. For new uses, TECHRON engineering gladly offers assistance in amplifier selection and modification.

Definition & Explanation of V-I Graph Terms

AC Line Fuse Blows: A demand for continuous DC, 20 amp output will cause the line fuse to blow. Protection circuitry allows excursions of AC (even square wave) output demands well beyond this point.

Mid-Frequency Burst Limit: Varied signal burst demands will generate varied results. This is a "medium" level of demand. At loads below 4 ohms, and with a low duty cycle, a "step" effect will occur, as protection circuitry monitors output signal history to set limits. With higher duty cycle, the "step" effect decreases, and with loads over 4 ohms, amplifier response is instantaneous.

Short Circuit Continuous Limit: The 7560's protection circuitry will permit a short circuit at the output up to +/− 24 amps. However, overheating will result and the 7560's thermal switches will place the amplifier in Standby.

Shaded Area: AC signals, because of their constantly varying strength, allow a larger output range than DC. With AC signals, the limiting circuitry constantly varies, depending on the history of the output. The graph is most helpful here, where output limits will vary constantly.

Max. AC Limit: With a sine wave input, and low load impedance, the protection circuitry allows this output for a very short time.

Max. Continuous AC Power: Self explanatory. Applies to loads above 2.7 ohms.

Min. AC Limit: With extremely low impedance loads, the AC limit might be this low in a worst-case burst mode of use.

Load Impedance and Inductance: Because input signal frequency, load inductance, load impedance all affect output limits, use the V-I Graph as a guide to amplifier performance. Contact TECHRON engineering for assistance in difficult or innovative applications.